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DEPARTMENT OF THE INTERIOR
HAROLD L. ICKES, SECRETARY

BUREAU OF MINES
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INFORMATION CIRCULAR

PROPOSED METHODS AND ESTIMATED COSTS OF MINING OIL SHALE AT RULISON, COLO.

BY

E. D. GARDNER AND CHARLES N. BELL

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By E. D. Gardner[2/] and Charles N. Bell[3/]

CONTENTS

1/ The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Information Circular 7218."

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CONTENTS (Cont'd.)

CONTENTS (Cont'd.)

ILLUSTRATIONS

ILLUSTRATIONS (Cont'd.)

INTRODUCTION

Oil shale, a long-considered potential source of motor fuel in the United States, is found over an extensive area in the Green River formation in Colorado, Utah, and Wyoming.4/

Oil has been retorted commercially from shale in Scotland for many years,5/ and work done by the Bureau of Mines and other investigators has shown that it is technically feasible to extract oil from American shales.6/ By refining, the shale oil may be converted into marketable products similar to those manufactured from crude petroleum.

The present paper, which was finished in 1936, discusses methods that would be adaptable to mining certain American shales, and the treatment applies specifically to conditions in the Green River formation on Naval

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4/ Woodruff, E. G., and Day, D. T., Oil Shale of Northwestern Colorado and Northeastern Utah: Geol. Survey Bull. 581, 1915, pp. 1-22.
Winchester, D. E., Oil Shale in Northwestern Colorado and Adjacent Areas: Geol. Survey Bull. 641, 1917, pp. 139-198.
Winchester, D. E., Oil Shale of the Vinta Basin, Northeastern Utah, and Results of Distillation of Miscellaneous Shale Samples: Geol. Survey Bull. 691, 1918, pp. 27-55.
Winchester, D. E., Oil Shale of the Rock Mountain Region: Geol. Survey Bull. 729, 1923, 204 pp.

5/ Gavin, Martin J., Oil Shale - An Historical, Technical, and Economic Study: Bureau of Mines Bull. 210, 1924, 201 pp.

6/ Gavin, Martin J., and Desmond, John S., Construction and Operation of the Bureau of Mines Experimental Oil-Shale Plant, 1925-1927: Bureau of Mines Bull. 315, 1930, 153 pp.

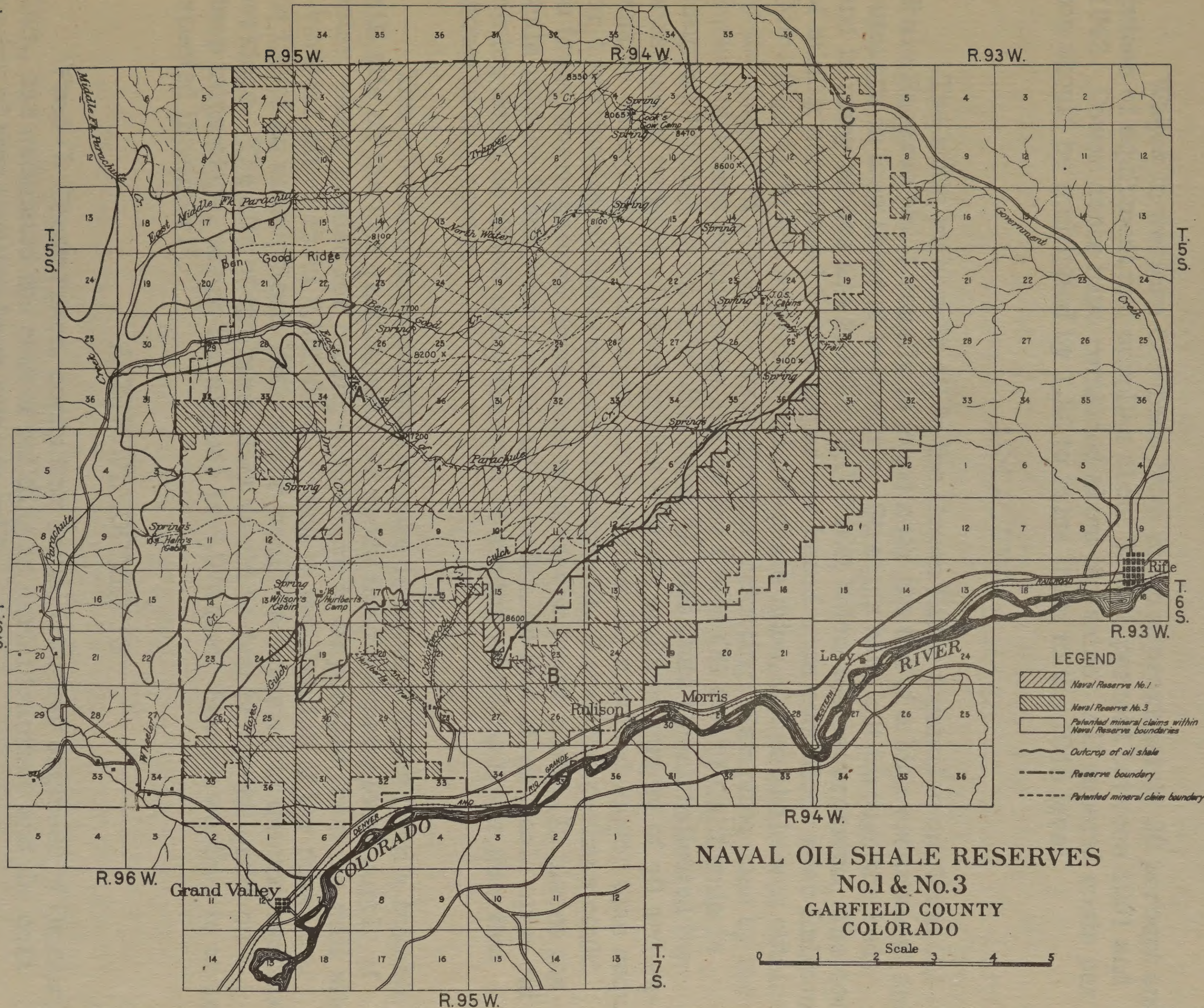

Figure 1.—Naval Oil shale reserves No. 1 and No. 3, Garfield County, Colo. (from Bureau of Mines Bulletin 315, Construction and Operation of the Bureau of Mines Experimental Oil-Shale Plant, 1925-27, by Martin J. Gavin and John S. Desmond, 1930, p. 12.)

Oil Shale Reserve No. 1. Estimates of mining costs, which were calculated on wages paid and prices of equipment and supplies in 1931, are based on assumptions that are clearly stated.

Wages in western Colorado have risen approximately 20 percent and prices of equipment and supplies about 33-1/3 percent between 1931 and 1942. Power costs have remained about the same. All general costs per ton should be multiplied by 1.22 to raise them to the 1942 level.

LOCATION

The shale richest in oil in the Green River formation on Naval Oil Shale Reserve No. 1 usually is found near the top of a high escarpment and outcrops in long lines of bold cliffs. Streams have cut through the beds and in many places are 2,000 to 3,000 feet below the escarpment. The costs of mining considered in this paper are based upon conditions near Rulison, Colo. (fig. 1), at the experimental oil-shale mine, where shale was obtained by the Bureau of Mines for experimental retorting. Sampling done by the Bureau of Mines at this mine and by the Union Oil Co. of California in diamond drilling on an adjoining tract of Parachute Creek indicated the presence of an area of shale having a fairly uniform content of oil and extensive enough to permit large-scale mining for a period longer than required for amortization of the necessary investment. Locations perhaps could be found where natural conditions would favor lower costs. In places the shale may be found with a small overburden, so that large-scale open-cut mining could be done; if so, the cost of mining might be lower than that shown in this paper.

The oil-shale area considered here is about 2 miles from a suitable mill site on the Colorado River. As there is no adequate local supply of water, water needed for mining would have to be pumped from the mill site - a vertical lift of about 2,500 feet. Owing to the location of the mine near the top of an escarpment, little water would be expected in the underground workings. The site of the mine plant would be just below the cliffs on a steep talus slope, where the altitude is 7,976 feet. Severe weather is to be expected in winter.

ACKNOWLEDGMENTS

Fred C. Carstarphen, consulting aerial tramway engineer of Denver, Colo., has estimated the cost of building an aerial tramway and the cost per ton of transporting from mine to mill.

The mining-machinery houses of Denver freely quoted prices on machinery needed to equip the mines.

Charles H. Johnson[7] helped the authors to calculate costs and design some of the details of the mining methods shown in this paper. W. R. Storms[8] assisted with the final revision.

DEPOSITS

The shale contains oil in varying amounts over a considerable thickness. Figure 2[9] shows the oil content of a 1,350-foot section of shale, as determined by the Union Oil Co. of California in drilling on Parachute Creek near Rulison, Colo. Figure 3[10] shows the logs of the richest section of shale at the Bureau of Mines experimental mine and of a corresponding section on Parachute Creek. The marker is a 6-inch bed of iron-stained limestone.

Table 1 gives the average thickness and average yield per ton of shale for three groups of beds in mining heights of the same section. The beds of Group B include those in Group A, and Group C contains the layers of the other two groups. Methods and costs of mining the shale in three thicknesses - 20, 44, and 106 feet - are considered in this paper.

Before mining operations are begun, the beds to be mined should be sampled thoroughly and systematically to check the previous sampling.

The specific gravity of oil shale varies inversely as the oil content. Upon the bases of specific gravity given by Winchester[11] and by Gavin,[12] which range from 1.4 to 2.2, the following tonnage factors have been used in estimating tonnages in the above three mining thicknesses: 20-foot bed, 16 cubic feet a ton; 44-foot bed, 15.5 cubic feet a ton; 106-foot bed, 15 cubic feet a ton.

The shale beds are fairly uniform in stratification,[13] although in places they are quite irregular. The layers range in thickness from a few

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7/ Assistant mining engineer, Bureau of Mines, Tucson, Ariz. (Mining engineer at time of revision in 1942.)
8/ Mining engineer, Bureau of Mines, Tucson, Ariz.
9/ Gavin, Martin J., and Desmond, John S., Work cited in footnote 6, p. 33.
10/ Work cited in footnote 6, p. 34.
11/ Winchester, D. E., Oil Shale of the Rocky Mountain Region: U. S. Geol. Survey Bull. 729, 1923, p. 15.
12/ Gavin, M. J., and Sharp, L. H., Some Physical and Chemical Data on Colorado Oil Shale: Bureau of Mines Rept. of Investigations 2152, 1920, 8 pp.
13/ Gavin, Martin J., and Desmond, John S., Work cited in footnote 6, p. 26.

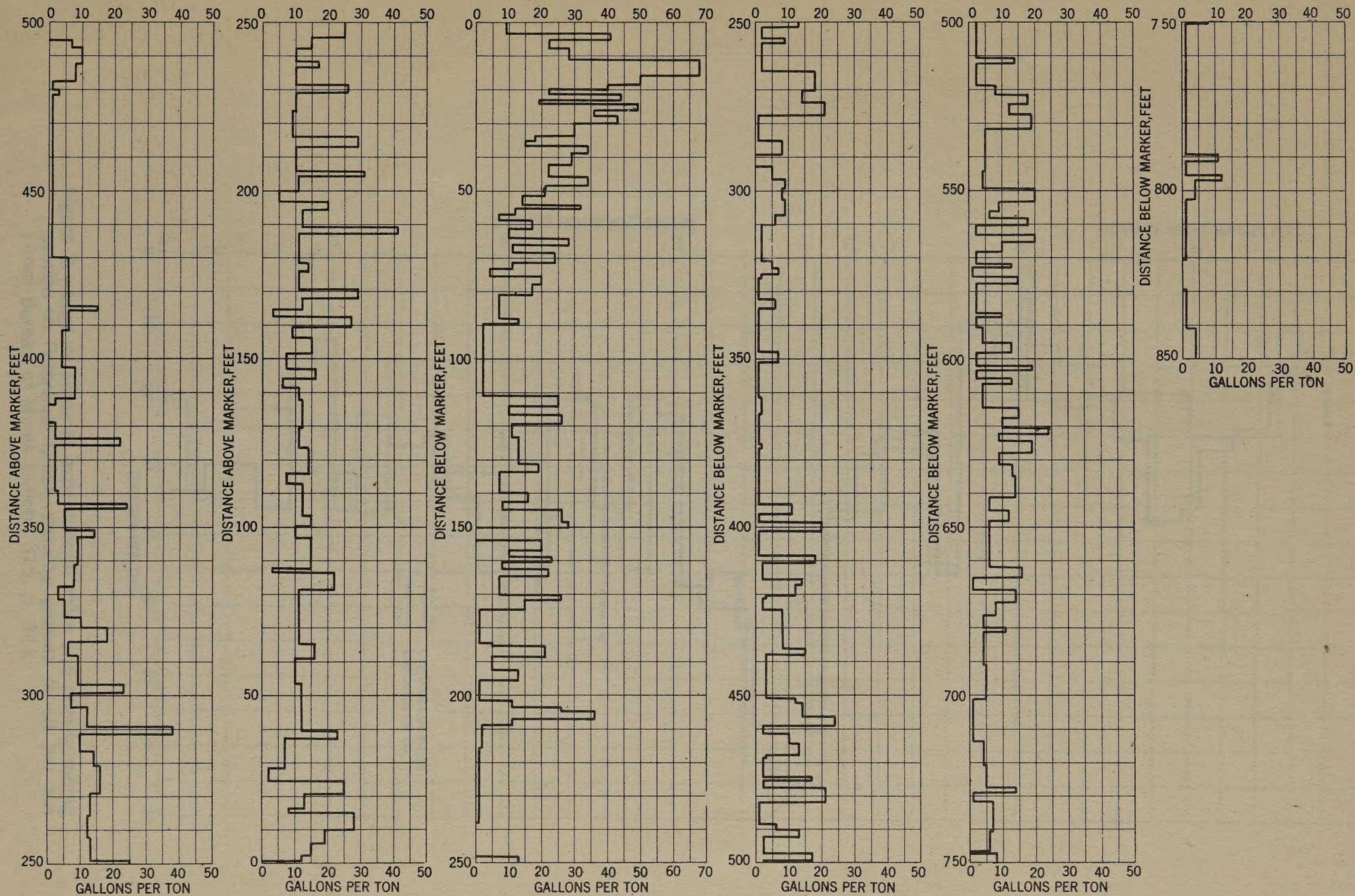

Figure 2.—Log of Green River formation showing gallons of oil per ton (from Bureau of Mines Bulletin 315, p. 33; data supplied by Union Oil Co. of California).

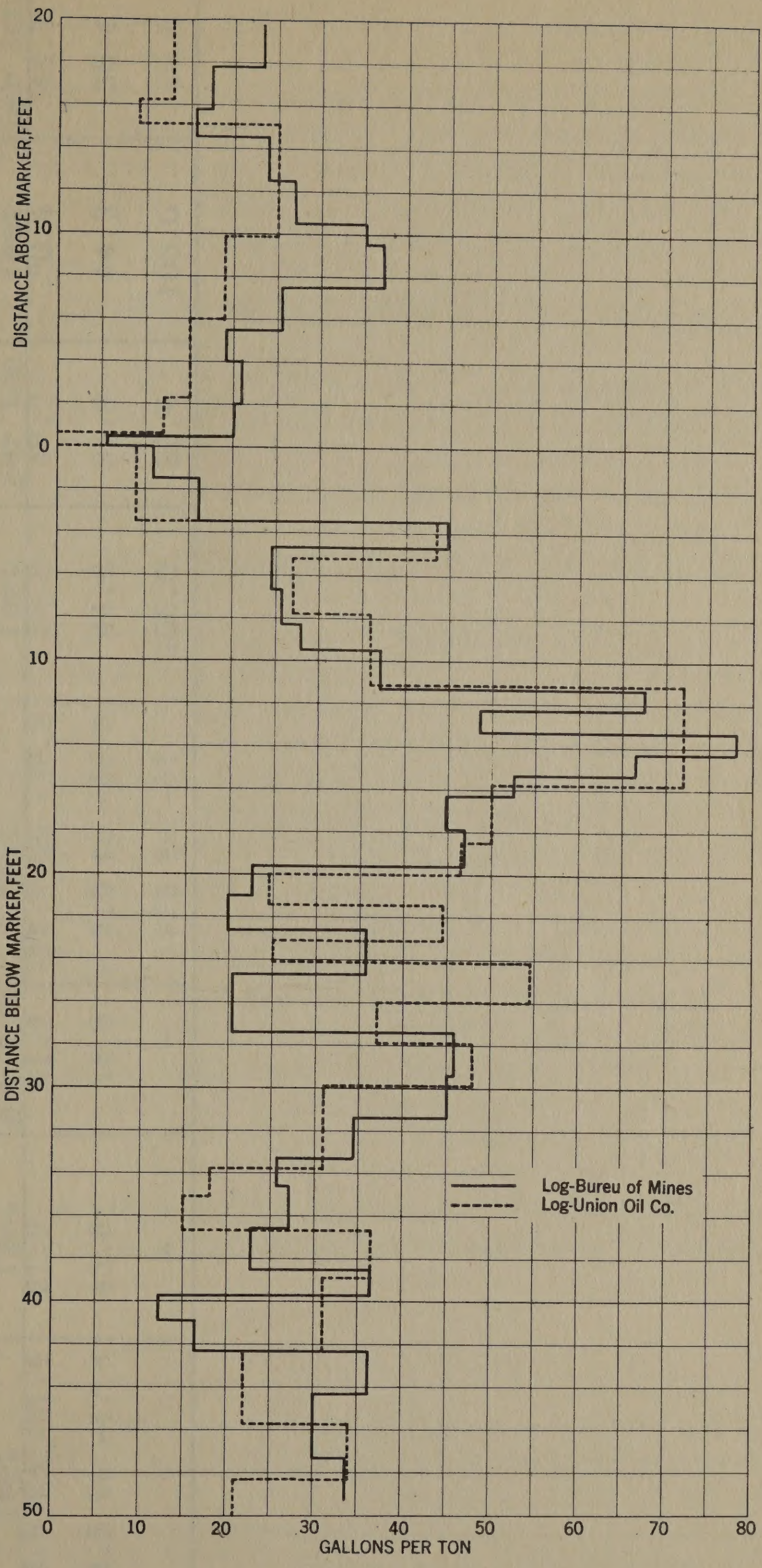

Figure 3.—Logs of shale at experimental mine and corresponding section on Parachute Creek, showing gallons of oil per ton (from Bureau of Mines Bulletin 315, p. 34).

TABLE 1. - Average thickness and yield of groups of shale beds in mining widths, Rulison, Colo.

Group	Bureau of Mines sampling: Distance from marker, feet	Bureau of Mines sampling: Thickness, feet	Bureau of Mines sampling: Average yield, gallons per ton	Union Oil Co. sampling: Distance from marker, feet	Union Oil Co. sampling: Thickness, feet	Union Oil Co. sampling: Average yield, gallons per ton	Average thickness, feet	Average yield, gallons per ton
A	-9.5 to -31.4	21.9	41.4	-11.1 to -29.9	18.8	47.2	20.4	44.3
B	-3.5 to -47.3	43.8	34.8	- 3.5 to -48.3	44.8	35.9	44.3	35.4
C	-	-	-	+25 to -81	106.0	25.4	106.0	25.4

inches to several feet, and bedding planes form planes of weakness. Thin layers of mud (locally called "mud slips") are present in a few places along bedding planes. The formation is nearly flat, the dip usually being about 2° but ranging up to 4°. Major jointing planes are prominent in individual beds and form planes of weakness through the shale. The shale is hard and tough and breaks across the beds with a conchoidal fracture, except where the break is influenced by jointing.

Characteristics of the Shale That Would Affect Mining

The roofs of rooms stand well, as shown by the workings at the experimental oil-shale mine. A room 30 feet across and 100 feet long has stood for two years with but little spalling. From examination of these workings it is considered that rooms 30 feet wide can be mined safely. However, owing to the "mud slips," it would appear advisable to run headings at the top of the rooms so that the roof can be watched as the faces advance.

Owing to the bedded character of the deposits and as a result of the experience gained in mining to obtain shale for the experimental retorts, it is expected that the shale will break in flat slabs, some of them large. The method of mining the 20- and 44-foot thickness is predicated on this assumption, wherein provision is made for handling large slabs, and the shale is not to be drawn through chutes until after it is crushed. A caving method has been worked out for mining the 106-foot thickness. As it is expected that the shale will break into large pieces, raises larger in cross section than in metal mines would be necessary. The bedding planes and jointing are expected to allow the shale to cave when a large enough area has been undercut. The first material drawn from the stopes probably would be coarse, but flat slabs would be broken to some extent by the uneven movement of the broken mass as it traveled downward. After the initial "draw," the shale should come to the draw points in sizes that could pass through the grizzlies readily.

The Bureau of Mines [14/] has found that oil-shale dust is explosive, and precautions to prevent dust explosions would be necessary in mining the shale.

MINING METHODS

Because the shale lies in flat beds, a room-and-pillar method would be the most satisfactory for mining and the 20- and 44-foot thickness of

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14/ Allison, V. C., and Bauer, A. D., Explosibility of Oil-Shale Dust: Chapter in Studies of Certain Properties of Oil Shale and Shale Oil, Bur. of Mines Bull. 415, 1938, pp. 75-81.

shale. The proposed plan does not provide for mining the pillars. Because of the hazard to men working under the high back, it is considered unsafe to work the 106-foot bed by an open-stope method; hence, the caving method is suggested.

The minimum tonnage considered would yield 2,000 barrels of oil daily, based upon Bureau of Mines assays and the assumption that 95 percent of the oil would be extracted in the retorts. As a barrel of oil contains 42 gallons, 2,000 tons daily mined from the 20-foot bed (average yield, 44.3 gallons a ton) would supply 42.1 gallons (95 percent of 44.3) by $\frac{2,000}{42}$ = 2,000 barrels a day $\left(\frac{95 \text{ percent of } 44.3 \times 2,000}{42}\right)$. It is probable that refineries of larger capacity would give lower refining costs. Four thousand tons daily from the same bed would produce 4,000 barrels a day. Five thousand tons daily from the 44-foot bed (average yield 35.4) likewise would supply 4,000 barrels daily $\left(\frac{95 \text{ percent of } 35.4 \times 5,000}{42}\right)$.

Assuming a 10-percent dilution of the group C shale (having an average yield of 25.4 gallons a ton) by overlying shale containing about 10 gallons of oil a ton, 10,000 tons daily from the 106-foot bed would produce 5,380 barrels a day.

Relatively low costs could be expected in mining the oil shale, as equipment best-adapted for the purpose could be procured and the most modern practices followed. It would not be necessary to fit the plan of development to existing workings or to use machinery already on the ground.

The costs given in this report are based upon the average of those obtained where the best practices are followed under similar conditions. Mining costs probably would be higher during the first year or two than later, after the operations have become well-organized and the crews properly trained.

As the beds are flat and outcrop at the surface, no hoisting would be necessary. Mining would begin about 400 feet from the portal of the main entry. This distance would be left so that the cliffs would not be weakened by subsidence and thus cause damage to the surface plant by loosened shale rolling down the steep mountainside. The shale would be transported from the mine to a treatment plant by aerial tramway.

Mining 2,000 Tons Daily from the 20-foot Bed

A panel system of mining is shown in figure 4. The block shown contains 20 panels and would supply 2,000 tons daily for 7 years. Costs are based upon the assumption that mining would begin at the back of the block; rooms would be started at the outer ends of the panels. The advantages of such a system would be that any ground subsidence that might occur as a result of failure of pillars would not interfere with subsequent operation. In addition, a better system of ventilation could be maintained. Other factors, however, probably would make it desirable to start mining the outer end of the block. A disadvantage of the retreating system is that about a year would be required to get the mine ready for production, and all of the overhead would have to be charged against this preliminary development work. Another and serious disadvantage is that the development work for a panel would be done beyond the producing area, and new panel entries would have to be opened from the main haulage track, with the possibility of delaying the output of shale and of breaking air and water lines. With the advancing system, all development work would proceed past the producing area and would not interfere with production. If the retreating system were adopted, all entries probably would be started before the permanent piping and wiring were put in, which would increase the cost per foot to some extent. With the advancing system, ventilation could be supplied by running adits at the outside of the block for the return air.

The panels are 1,130 feet long (fig. 4), with 50-foot pillars between panels and on each side of the main entry and 100-foot barrier pillars between blocks. An 8- by 10-foot entry is run through the panel and 30-foot rooms are turned off on each side with 20-foot pillars between. The rooms are 150 feet long. The tonnage from each room would be $\frac{20 \times 30 \times 150}{16}$, or 5,625 tons, assuming that the tonnage from the entry and overbreak in the pillars would equal the shale left in the narrow end of the rooms at the room necks. In a panel of 46 stopes the tonnage would be 258,750 tons. A 20-panel block would contain 5,175,000 tons.

The broken shale is to be dragged from the rooms to the panel entry by scrapers and dumped on a drag conveyor. The conveyor, in turn, would discharge the shale into cars in the main entry for transportation to the surface. The use of power shovels for loading the shale directly into the cars in the rooms was considered impractical because of the large, flat slabs of shale, which would be difficult to load.

Concentration of stoping operations as much as possible without causing congestion would be desirable, both to allow easier supervision and to permit

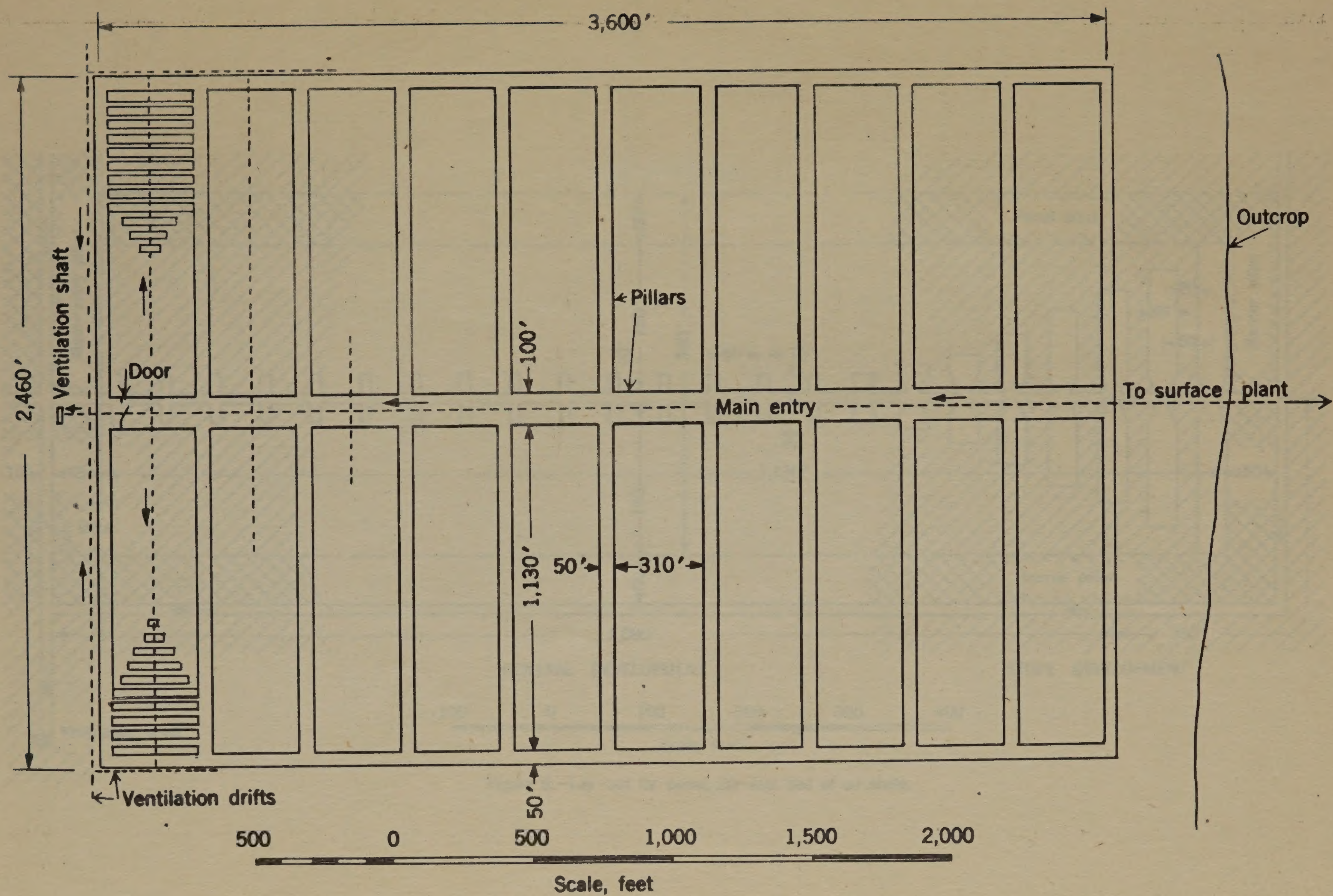

Figure 4.—Plan of 20-panel section.

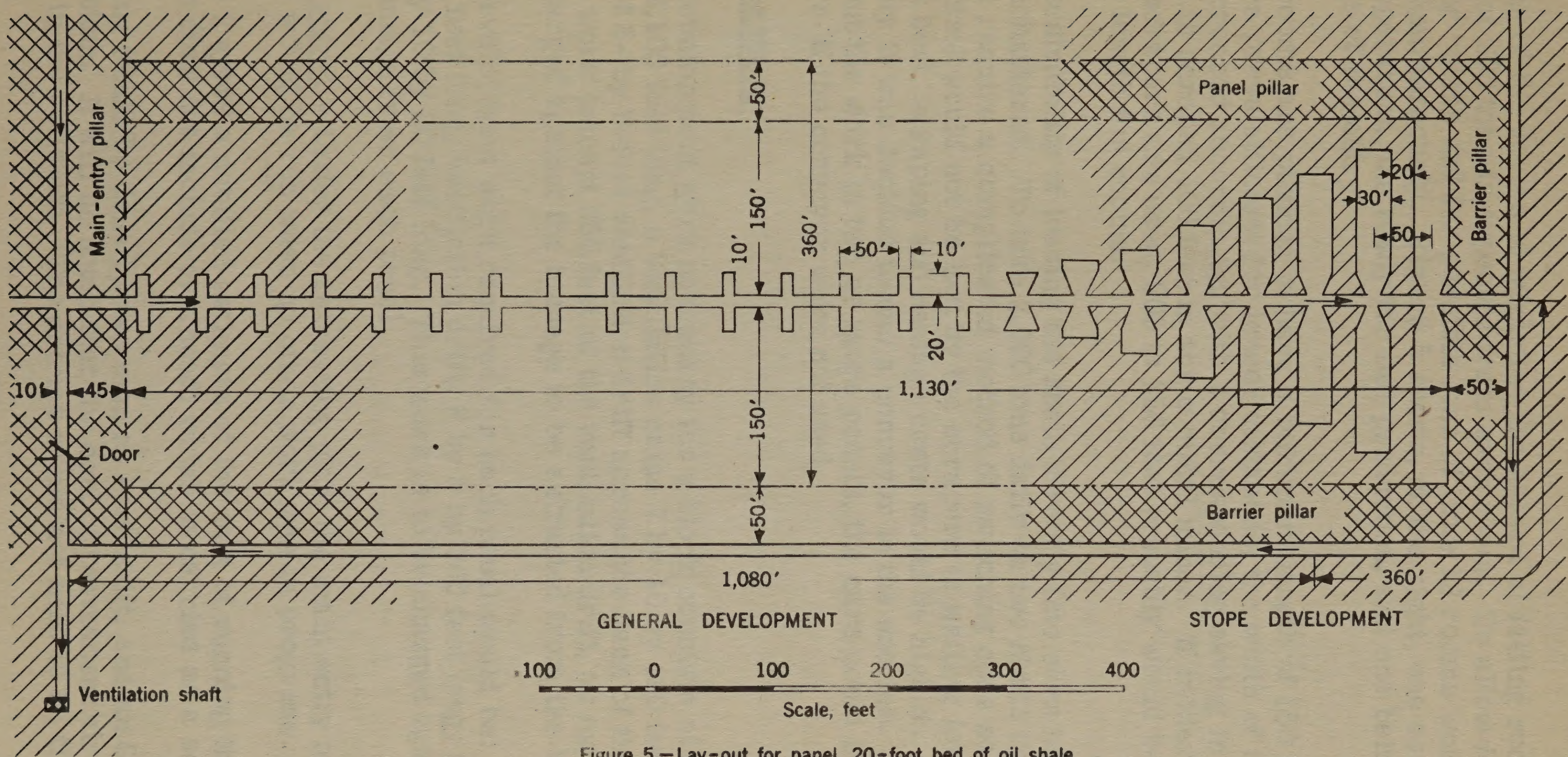

Figure 5.—Lay-out for panel, 20-foot bed of oil shale.

rapid mining of the rooms to minimize the hazard of falling rock. A daily production of 200 tons is expected from each room. To allow for starting and finishing rooms and for possible loss of time 12 rooms would be in operation simultaneously. Figure 5 shows, at the right, one completed room, six in full operation, one ready for full production, and one being prepared, on each side of the entry.

The rooms are planned to have a minimum length of 150 feet. Should the scrapers prove efficient for longer distances, the width of the panels could be increased accordingly, with a corresponding saving in development costs. Ore is scraped 400 feet in some metal mines. If modern scraper hoists and scrapers are used, 200 to 250 feet probably would be the most economical length for rooms.

The desirability of loading the shale directly into cars in the panel entry was considered. To take 2,000 tons daily on two shifts from a single entry would require a complicated method of switching cars so that unwarranted time would not be lost by the scrapers in waiting for cars to be spotted. At best, scraping and haulage costs would be higher. To obviate this difficulty it was decided to use a conveyor in the entries. However, by spreading out the work in two or more panels, the cars could be loaded by the scrapers if the conveyor were not used.

Development Work

The development work necessary for a block consists of a main entry 8 by 10 by 4,100 feet long, a ventilation raise 7 by 10 by 400 feet high, and 2,460 feet of 8- by 8-foot ventilation drift across the back of the block. The cost of this work (except 300 feet of the ventilation drift, as explained later) would be charged against the tonnage to be extracted from the block.

The development work required for each panel would be: Entry, 8 by 10 by 1,230 feet long; ventilation drift, 8 by 8 by 360 feet long; and 46 room necks, 10 by 10 by 20 feet long. This work is to be charged against the expected tonnage from each panel.

Main entry. - Under the retreating plan, the main entry and the ventilation raise would be run when no other work was in progress.

Table 2 gives a detailed estimate of the cost of running the main entry. This does not include overhead, which is carried as a separate item.

Drilling would be done by two men on each shift, and an 8-foot round could be broken. It will be noted that the cost of permanent air and water lines is included in the estimate. The entries would not need to be timbered.

TABLE 2. - Labor and supplies for running 8- x 10-foot main entry; no other operations in progress (2,000 tons; 20-foot bed)

	Number of men per day	Labor scale per shift	Amount
Labor, per day:			
Miners	4	$5.00	$ 20.00
Miners' helpers	2	4.50	9.00
Loader operators	2	5.00	10.00
Loader helpers	2	4.50	9.00
Locomotive operators	2	5.00	10.00
Locomotive helpers (switchmen)	2	4.50	9.00
Trackmen and pipemen	2	4.50	9.00
Compressor men	2	5.50	11.00
Blacksmith	1	6.00	6.00
Foreman	1	8.00	8.00
Shift bosses	2	6.50	13.00
Total per day (two 8-foot rounds			114.00
Per foot			7.13
Power, per day:			
Compressor, 60 h.p. at $4.05 per h.p. per month			8.10
Locomotive, 20 h.p. at $4.05 per h.p. per month			2.70
Fan motor, 20 h.p. at $4.05 per h.p. per month			2.70
Total			13.50
Per foot			.84
Supplies, cost per foot at mine:			
Powder, 13 lb. at $0.16 per lb			2.08
Fuse and caps			.19
Rails (40 lb. per yard)			1.00
Ties, 6 x 8 inches by 5 feet long on 2-1/2 feet centers, at $40 per M. bd. ft			.32
Air pipe, 8 in. diameter (delivered)			1.44
Water pipe, 3 in. diameter (delivered)			.41
Ventilation pipe (installed)			.50
Trolley wire (installed)			.50
Drills, steel, and miscellaneous supplies			.90
Total supplies per foot			7.34
Grand total			15.31
Allowance of 15 percent for lost time and contingencies			2.30
Estimated cost per foot			17.61

The cost per ton for the 4,100-foot main entry charged against the shale in the block would be $\frac{4,100 \text{ by } \$17.61}{5,175,000}$ or $0.014.

Ventilation raise. - The same price per foot is taken for the ventilation raise. This raise would not need to be lined, and only temporary timber would be carried up while the raise was extended. The cost of the 400-foot raise, as charged against the shale in the block, would be $0.001 a ton.

Ventilation drift. - The section of the ventilation drift 360 feet in length back of each panel would be driven as a part of the panel-development work and charged against the shale in the panel. The drift along the side of the panel would be charged against the shale in the block. The length of the drift from the main entry, along the side of the panel, and up the end to the panel entry would be 1,440 feet. Allowing 360 of these 1,440 feet as development work for the panel, 1,080 feet would be charged against the block. As the block contains two rows of panels (fig. 4), the total length of the ventilation drift charged against the block would be 2,160 feet. The cost of running the ventilation drift, which is smaller in cross section than the main entry, is estimated at $15.00 a foot. The charge against the shale in the block would be $0.006 a ton.

The total cost of preliminary development work that is to be debited against the shale as mined as a deferred charge is $0.021 a ton.

Panel entries and room necks. - In running the panel entries, the broken shale would be loaded into cars with mechanical loaders. The broken shale from the room neck and that broken in widening the entry to the full width of the stope also would be handled in the same manner.

The room necks would be run concurrently with the entry after the face was advanced far enough so that the various operations would not interfere with each other. The broken shale from the heading and the room necks could be handled with the same loader.

After the work was well-organized and crews were trained for specific jobs, a bonus or contract system would be established, under which system it is estimated that the panel entries and room necks could be run for $8.49 or less a foot.

Table 3 gives details as to the cost of driving panel entries and room necks, assuming that an 8-foot round is drilled by a three-man drill crew and removed by a single mechanical-loader crew during each shift. The panel-development work would need to carry only its share of the overhead.

TABLE 3. - Cost of labor and supplies for running 8- by 10-foot panel entry

Items for two 8-foot rounds	Total cost per day	Cost per foot
Four miners at $5 per shift	$20.00	$1.25
Two miners' helpers at $4.50 per shift	9.00	.56
One loader operator 1/ at $5 per shift	5.00	.31
One loader helper at $4.50 per shift	4.50	.28
Supervision	3.50	.22
Steel sharpening, 60 bits at $0.10 each	6.00	.38
Drill repairs, 4 machines at $0.60 each	2.40	.15
Explosives, 13 lb. per foot at $0.16	33.28	2.08
Track and pipe	16.00	1.00
Other supplies	9.00	.56
Power for drills at $0.75 per drill shift	3.00	.19
Power for mechanical loader	1.50	.09
Total	113.18	7.07
Plus 20 percent for delays and other contingencies	22.64	
Grand total	135.82	8.49

1/ 1/2 shift only on each shift, or one man a day. Mechanical loader at 50 to 75 cu. ft. a minute can clean up face in half shift.

The labor efficiency is about 1.6 foot a man-shift. The labor for sharpening steel and repairing drilling machines, together with power, is included in the total charged against stoping, which gives a further percentage for contingencies.

A cost of $10 per foot is allowed for the ventilation drifts; after the work is well under way a substantially lower cost probably could be obtained.

The cost per ton of shale in the panel of the 1,230-foot panel entry, 46 room necks 20 feet long, and 360 feet of ventilation drift would be $0.040, $0.030, and $0.014, respectively, a total of $0.084.

The segregation of the above charges into labor, supervision, drills and steel, power, and other supplies is shown in the table at the end of this section of the paper giving the summary of costs.

Stoping

Before actual stoping began, the panel entry would be run, the room necks cut, the stope started, the conveyor installed, and the scraper hoist set up.

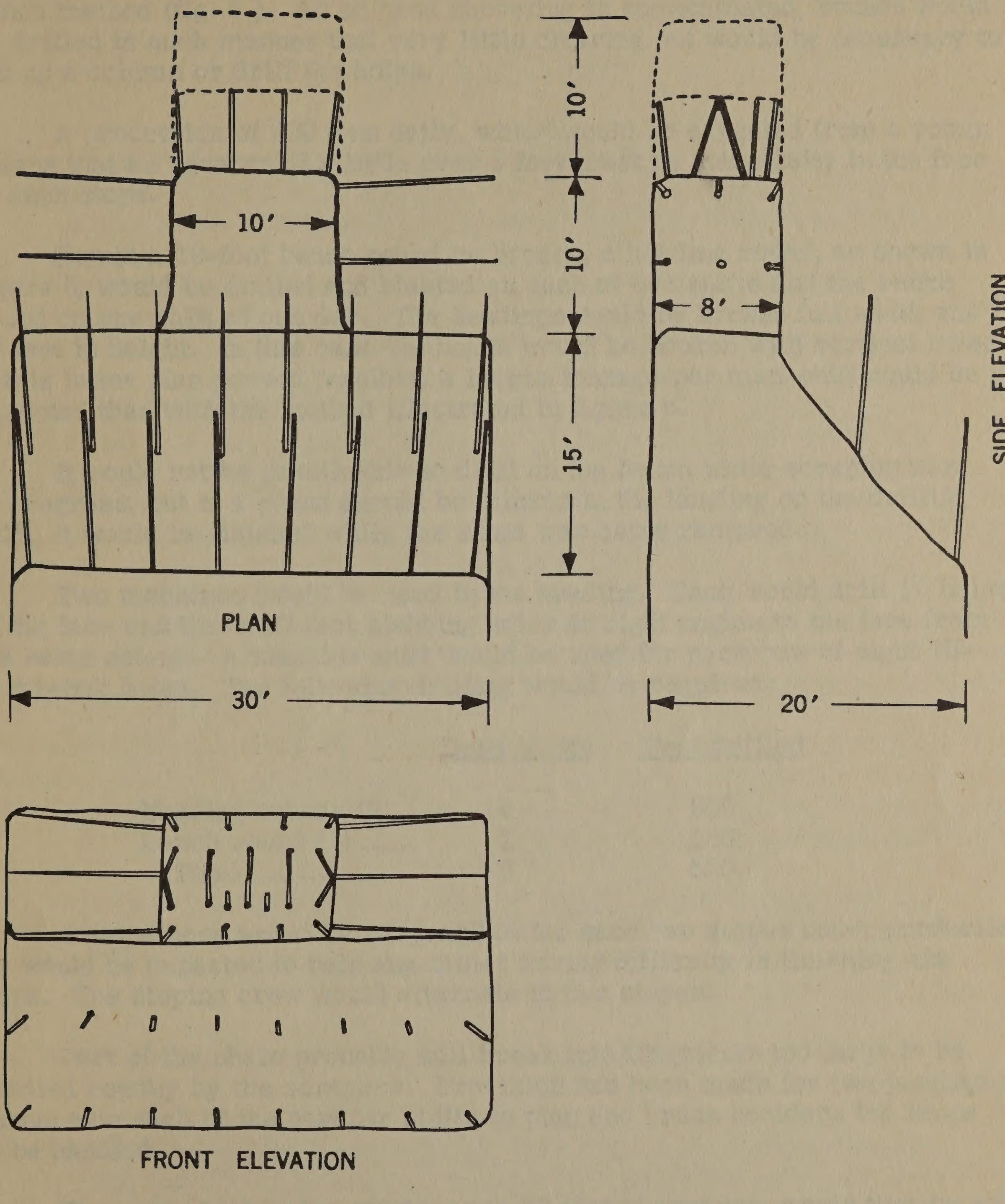

Figure 6.—Method of drilling in room in mining 20-foot bed of oil shale.

Drilling and blasting. - The rooms would be stoped by a heading-and-bench method (fig. 6.). As no hand shoveling is contemplated, rounds would be drilled in such manner that very little clearing out would be necessary to set up a column or drill the holes.

A production of 200 tons daily, which would be expected from a room, means that an advance of a little over 5 feet must be made daily in the face of each stope.

Should a 10-foot bench round be broken, a heading round, as shown in figure 6, would be drilled and blasted on each of two shifts and the bench round on one shift of one day. The headings could be broken full width and 10 feet in height. In this case the bench would be broken with vertical holes. If this latter plan proved feasible, a larger tonnage per man-shift could be expected than with the method illustrated in figure 6.

It would not be practicable to drill on the bench while scraping was in progress, but if a round should be missed in the heading on the drilling shift, it would be finished while the shale was being removed.

Two machines would be used in the heading. Each would drill 10 holes in the face and three 10-foot slabbing holes at right angles to the face from the same set-up. A machine shift would be used for each row of eight 10-foot bench holes. The following drilling would be required:

	Drill shifts	Feet drilled
Heading rounds (2)...	4	360
Bench round (1)	2	160
Total	6	520

A stope boss would be responsible for each two stopes under production. He would be expected to help any miner having difficulty in finishing his work. The stoping crew would alternate in two stopes.

Part of the shale probably will break into fragments too large to be handled readily by the scrapers. Provision has been made for two jackhammer runners on each of the scraper shifts to plug and break boulders too large to be handled.

The cost of labor for stoping, per 10 feet of advance, would then be as follows:

10 shifts of miners at $5.00	$50.00
1 shift boss	5.50
Total	55.50

The cost per ton would be

$$\frac{55.50}{375}, \text{ or } \$0.148.$$

The cost of labor per ton for repairing drills and sharpening steel is included in the estimate for surface labor costs. The cost of steel, drill parts, and other supplies is estimated at $0.05 per ton of shale mined.

The plan of drilling shown applies to the most difficult breaking conditions likely to be encountered. Production of 33 tons per drill shift is indicated; it is probable that this would be exceeded when the best practice for the conditions existing had been determined.

The top slabbing holes, which are shown in figure 6, are 5 feet apart horizontally and 4 feet apart vertically. The bench holes are 6 feet apart vertically and 4 feet horizontally. Horizontal bench holes have an advantage in that a smoother bottom would be provided for scraping. Drilling the top slabbing holes as described fits into the drilling plan but may tend to weaken the pillars. By drilling the holes across the beds fewer large fragments would be expected, although more holes would be required to break the rounds. A compensating saving could be expected in that fewer plugger-machine shifts would be needed.

Drilling the flat holes on the face of the bench presents difficulties. Hand-held drills for this purpose would be suspended by a small rope block from a tripod having adjustable legs made of pipe. The bench could be broken with vertical holes if found desirable.

Explosives. - Forty-percent-strength gelatin dynamite was used satisfactorily at the experimental oil-shale mine. Shale or shale dust was not ignited by the explosive during the operations; however, only a limited amount of shale was mined underground.

The shale is combustible; moreover, under some conditions, shale dust forms an explosive mixture with air.

Before blasting, all settled dust in the stopes would be washed down or sprinkled. No evidence exists that explosive gases would be encountered. All blasting is to be done electrically after the crew has left the mine.

In addition to the standard precautions taken to prevent fires or explosions it would be preferable to use a permissible explosive for blasting the shale. For a coal-mining explosive to be classed as "permissible," only 1-1/2 pounds can be shot in any one hole; however, larger quantities than this would be needed per hole to break the shale.

A carbonite "permissible" probably would break the shale, but the resulting gases would contain an excessive amount of carbon monoxide. Use of a "permissible" would necessitate a better ventilating system and require a longer interval between shifts than if blasting were done with a gelatin dynamite. It would be necessary to blast boulders during the lunch hour under the plan of mining being considered. This requires an explosive such as gelatin, which does not produce much carbon monoxide.

Forty percent-strength gelatin dynamite was used and proved satisfactory at the experimental oil-shale mine. Shale or shale dust was not ignited by the explosive during the operations, but as only a relatively small tonnage of shale was mined, this experience cannot be considered conclusive. The mining operations, however, indicated the quantity of this explosive required per hole to break the ground. The methods of blasting and the cost of explosives discussed in this paper are based upon use of the 40-percent-strength gelatin dynamite. The problem should be studied further before actual operations began.

The explosive required for a 10-foot advance in a stope would be as follows, using 40-percent-strength gelatin in 1-1/8- by 8-inch cartridges for stoping:

	Cartridges
2 heading rounds, 20 holes each, average 5 cartridges per hole	200
12 top-slabbing holes, average 8 cartridges each...	96
16 bench holes, average 10 cartridges each	160
	456

456 cartridges at 0.54 pound each = 246 pounds.

Pound per ton = $\frac{246}{375} = 0.66$.

Explosive cost per ton: 0.66 x \$0.16 = \$0.106.

Transportation

Scraping. - Electric triple-drum hoists will be used for pulling the scrapers. The hoists will have a rope pull of over a ton and a rope speed of over 200 feet a minute at full load. Each hoist weighs about 6,000 pounds. They will be mounted on a substantial plaftform over the conveyor in the entry (fig. 7), from which place the hoist can pull from the room on either side. The same scraper can be used by pulling it from one side to the other over the drawbridge.

Heavy scrapers will be needed to handle the large, flat boulders. A box-type scraper would ride over the large boulders, and a straight blade-type would not have sufficient capacity. A scraper (fig. 8) used by the Tennessee Zinc Co. at Mascot, Tenn., has a curved blade and works satisfactorily on rocks that break similarly.

Two men should be able to handle 200 tons a shift from a room, as it will not be necessary to delay while waiting for cars, and an ample supply of broken shale will be available - 400 tons after each round.

The daily labor cost would be:

12 scraper men at \$5 per shift $\frac{\$60}{2,000}$, or \$0.030 per ton

12 helpers at \$4.50 per shift $\frac{\$54}{2,000}$, or \$0.027 per ton

Scraper boss, 2 shifts at \$6 per 2,000 tons	\$0.006	per ton
Total labor	\$0.063	per ton

The power consumed by the scraper hoists is 270 horsepower a day, or, at \$4.05 per horsepower a month, a total of \$36.45 a day (for continuous peak load). This gives a cost of \$0.018 a ton.

Scraping is charged with \$0.030 a ton for supplies and upkeep.

The total cost of scraping is therefore \$0.129 a ton.

Conveying. - Conveyors have been used only to a limited extent in metal mines but have proved satisfactory in coal mines. A conveyor system appears to fit in well with the method of mining shale herein proposed. The operators of scraper hoists will dump the loads near the hoists and can watch the loading. The sectional drag conveyor chosen is easy to install and follows irregularities of the floor.[15]

15/ Since 1931, after this paper was prepared, belt transportation has been adopted in a number of metal mines. Present (1942) standard installations using rubber belts probably would prove more practicable than the type described herein.

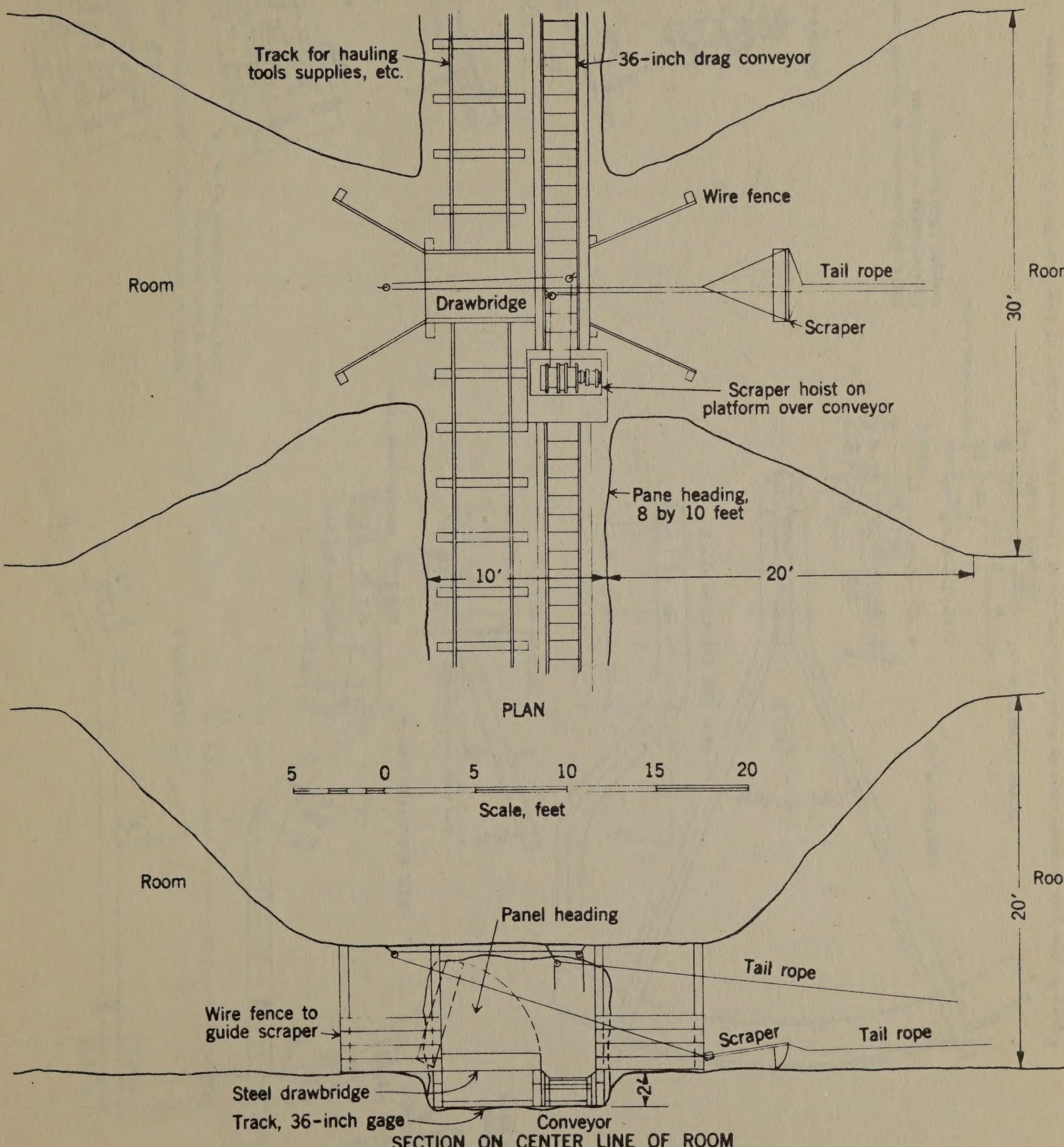

Figure 7.—Method of using scraper loading in 20-foot and 44-foot beds of oil shale.

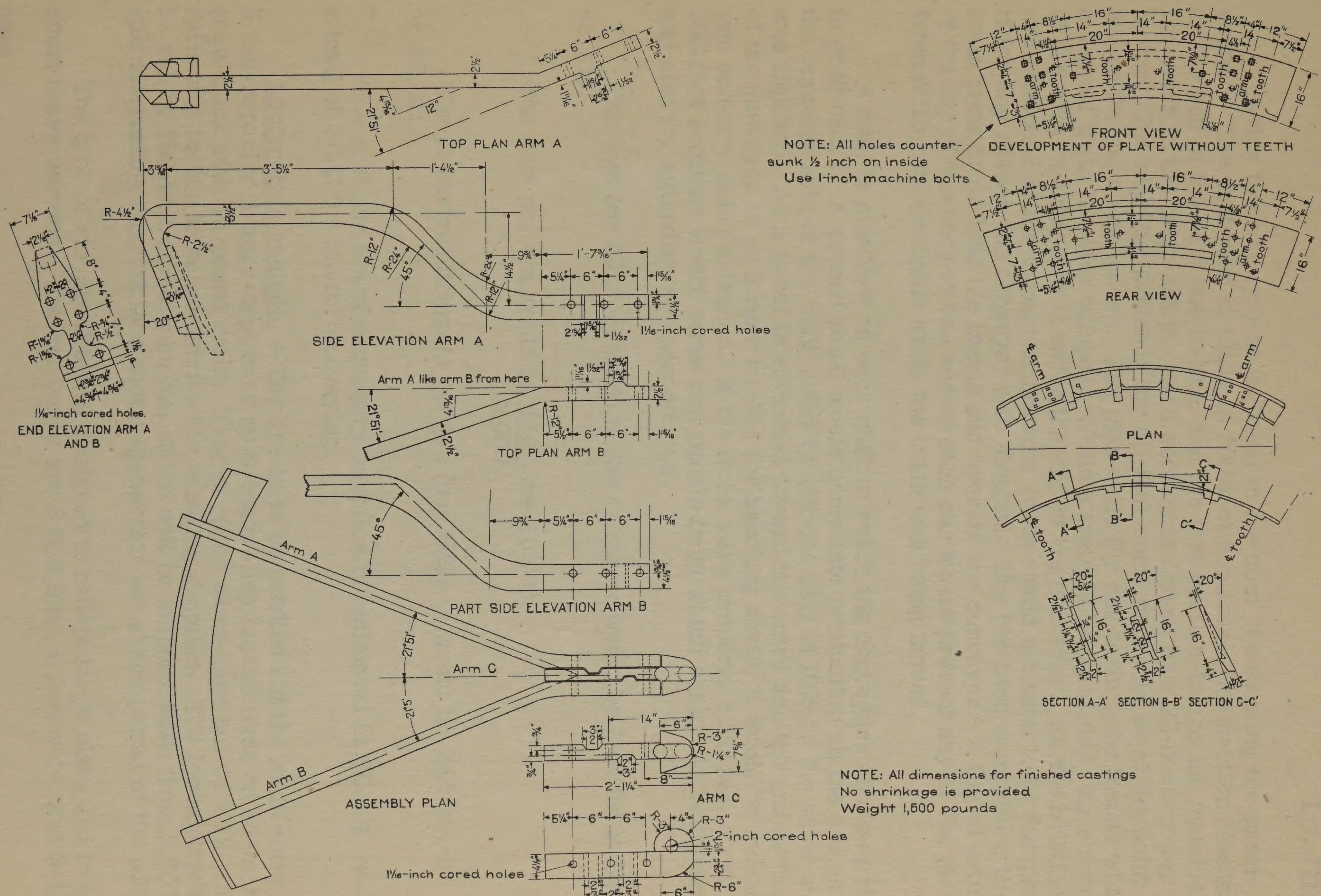

Figure 8.—Hoe-type scraper used by American Zinc Co. of Tennessee. Courtesy of American Zinc Co. of Tennessee.

Laying the conveyor is included in the cost of extending the panel entries. The conveyor is made in 300-foot sections. One section discharges on the end of the next one in line, and the last section dumps the material into cars in the main entry. Each section is driven by a 20-horsepower motor. The starting switches for all four sections would be at the point where the cars are loaded. The plan calls for one train to be loaded while a second train is being dumped. While a train is being loaded, the empties of the next would follow it under the end of the conveyor. As the hoistmen are stationed at the conveyor, scraper loads would not need to be dumped if for any reason the conveyor was stopped. The two men comprising the train crew could load the trains and operate the conveyor. A flared extension of the top of the body at one end of each car would prevent any of the shale from falling on the track while the train was being moved.

A man is provided on each shift to watch the conveyors and keep them in good order. A second panel would come into production as the one on the opposite side of the main entry or the one next in line on the same side was finished. As a panel is advanced toward the entry and the end section of the conveyor is no longer needed for handling shale, it would be moved into an entry being extended. If the work were properly balanced, eight 300-foot sections would serve two panels from which shale was being drawn and also for extending two new entries.

The cost for labor charged to the conveyor would be 2 shifts at $5, or $10.

The cost per ton would be $\frac{\$10}{2,000}$, or $0.005.

The power requirement per ton (see table 4) would be 0.95 kw.-hr., or $0.011.

The cost per ton of necessary supplies is estimated at $0.004, making a total of $0.020 a ton for conveying.

<u>Locomotive haulage.</u> - The ore is to be handled out the main entry in 5-ton-capacity Granby-type cars by 8-ton trolley locomotives on 36-inch-gage track with 40-pound rails. Tracks of the same gage but with 12-pound rails will be run in panel entries for handling supplies. The locomotives will be run by 250-volt direct current, which will be stepped down from 2,200-volt alternating current by a motor-generator set at the portal of the adit.

The type of car specified is designed to handle large slabs and to withstand heavy service. The car boxes are 8 feet long, 5 feet wide, and 3-1/2

TABLE 4. - Power requirements and costs for mining 20-foot bed, 2,000 tons daily

(Cost of power at $0.0075 per kw.-hr., or $4.05 per horsepower month continuous service

Item	Motors			Service per day, hours	Kw.-hr. per ton ore	Horsepower per ton of ore over 24 hours per day
	No.	Horsepower	Total horsepower			
Compressor..	1	1,000	1,000	16	5.97	$0.067
Two locomotives............	4	40	160	16	.95	.011
Two conveyors..............	8	20	160	16	.95	.011
Ventilation................	1	9				
Cut-off saw................	1	5				
Oil forge..................	2	3	44	12	.196	.003
General forge..............	1	2				
Lights and miscellaneous....	-	25				
Pump.......................	1	30	30	16	.178	.002
Scraper hoists.............	6	45	270	16		.018
Total mine-power requirement	-	-	1,394	-	-	.112
Crusher....................	1	100				
Do.........................	1	150				
Crusher conveyor...........	1	3				
Do.........................	1	7-1/2				
Tramway....................						.006
Total, crushing plant.....			260.5	8	.78	.006
Total, power requirements.			1,924.5			.124

feet deep and stand 68-1/4 inches above the rail. The dumping arrangement will be erected over the hopper of the primary crusher or over the shale bin, if one is used.

The main haulage track will be straight. Although the beds dip up to 4°, the block will be laid out so that the main track will have as nearly as possible a 1/2-percent grade in favor of the loaded trains and still keep it straight. With a new installation designed for the purpose and an adequate track, very few derailments should occur. The only curves in the track would be at the surface. The average haul would be about 2,000 feet. The cost of haulage, including a motor crew on development work, is estimated as follows:

Labor:

6 motormen at $5....................	$30.00
6 brakemen or motormen helpers at $4.50	27.00
Total	57.00

Labor cost per ton $\frac{\$57.00}{2,000} = \$0.028.$

The power requirement would be 0.950 kw.-hr. a ton at a cost of $0.011. The cost of supplies is estimated at $0.011 a ton; the total cost of direct haulage would be $0.050.

Ventilation

The ventilation system with the retreating system of mining is indicated in figure 4, in which arrows indicate the direction of the air currents. An exhaust fan would be placed on the surface at the collar of the ventilation shaft.

The main air current in the main adit would be drawn through the panel entry and thence through the ventilation drift to the raise. When two panels are being worked simultaneously, the circuit would be split. Doors in the main entry would be put in past the working area and would not interfere with tramming. Should further ventilation be required in the rooms, cross-cuts could be run through the room pillars when the face had advanced about half the distance, and air could be drawn directly through the stopes, the far end of the panel entry being closed with a door. As rooms and panels are finished, they would be bulkheaded off from the ventilation circuit.

Should mining be started near the portal of the entry, half of the block on each side of the entry would have to be ventilated separately by means of

fans at the portal of the ventilation drifts. The main entry would be the intake. The same footage per panel of ventilation drift would have to be driven in either instance. Ventilation drifts coming to the surface also would be used for transporting supplies.

Lighting. - As the shale is inflammable and the dust may be explosive, closed lights should be used. The men would carry electric cap lamps, and the faces of the stopes would be lighted by electric flood lights. The parts of the panel entries and the main entries where work was being conducted would be illuminated by the usual electric light. If explosive gases were encountered, all motors would have to be of the "permissible" type.

Crushing. - To handle the shale by aerial tramway, it must be crushed. The shale also requires crushing for retorting, and this crushing to the size required at the retorts would be done at the portal of the main entry. A crushing plant would consist of a 36- by 48-inch jaw crusher, which would take the run-of-mine shale and reduce it to pass an 8-inch opening. From the jaw crusher the shale would be fed by a 42-inch steel pan conveyor, 20 feet long, to a cone crusher, which would break the shale to pass a 2-1/2-inch screen. From here it would be taken by a 30-inch belt conveyor, 40 feet long, to the storage bin at the upper terminal of the tramway.

The crushing plant would handle 2,000 tons in 8 hours. Should a storage bin be provided, crushing could be done from midnight to 8 a.m., when the compressor plant would be idle, to keep down the maximum power load.

The cost of crushing is estimated below:

Labor, 2 shifts at \$5.00 = \$10.00 a ton, $\frac{\$10}{2,000}$	\$0.005
Power per ton (see table 4)	.006
Repairs and supplies	.019
Total	0.030

Difficulties can be anticipated in handling the flat, coarse material, as mined, through a gate or chute in an ore bin. A ball-and-chain gate would control the flow, but the flat blocks probably would cause arching. A storage bin ahead of the crusher would be desirable; however, unless a satisfactory feeder could be designed to permit uninterrupted feeding of the crusher, costs could be lowered by dumping the shale from the mine cars directly into the hopper of the primary crusher. This last practice is followed in open-cut copper mines, where coarse material is handled.

The large fragments probably could be handled through an 8- by 10-foot opening. The bottom of the bin under the opening would extend outward, forming an apron having sides tapering down to about 5 feet apart at the lower end. The end of the ore stream would rest at its angle of repose, beyond the end of the apron, on a pan conveyor running at right angles to the front of the bin. The shale would be drawn from the bin by the conveyor. Probably one man could keep the large slabs, which tend to hold back, barred down. Another man would be required to watch the crushers. By dumping the ore directly into the hopper of the first crusher, one man could run the crushing plant. The labor charge would be the same, whether the plant were run on one shift and the ore drawn from a bin, or on two shifts and the ore dumped directly into the crusher.

Total power requirements. - Power would be available in nearby mining districts and could be purchased at 3/4 cent per kw.-hr., or $4.05 per horsepower-month continuous service. Byproduct gas would be made in retorting the shale, and it is thought that enough power could be generated at the plant from this waste gas to supply the mine and plant.

The plant would be credited for the power at the rate at which it could be purchased from other sources.

Table 4 shows the total requirements for power and its distribution for mining 2,000 tons a day from the 20-foot bed.

Aerial tramway. - Fred C. Carstarphen, consulting aerial-tramway engineer of Denver, Colo., estimated that the cost of building a 2-mile tramway from the mine to a mill site in the river valley would be $200,000 and that the cost of transporting 2,000 tons of ore per 8 hours to the retorts would be $0.025 a ton.

Most of the mine supplies will be transported to the mine on the tramway from a railroad spur at the retorts.

The tramway will be of all-steel construction and have automatic-bucket loading and dumping devices. Each bucket will hold 3,300 pounds of shale.

General underground labor. - The daily wages of two timbermen, two trackmen, a pipeman, and a pipeman's helper are charged as general underground labor. This amounts to $0.019 per ton of shale mined.

Surface labor charged to underground mining. - The surface labor charged to mining is given in table 5. This amounts to $0.031 a ton. Miscellaneous surface labor also is shown in the table and amounts to $0.030 a ton.

TABLE 5. - Labor for mining 2,000 tons daily from 20-foot bed, including development

Classification	No. men per day (2 shifts)	Wage scale per shift (Jan. 1931)	Amount per day
Underground:			
Miners, in stopes	60	$5.00	$300.00
Miners on development	8	5.00	40.00
Miners' helpers on development	4	4.50	18.00
Loader operators on development	2	5.00	10.00
Loader helpers on development	2	4.50	9.00
Scraper hoistmen, stoping	12	5.00	60.00
Scraper-hoistmen helpers, stoping	12	4.50	54.00
Scraper bosses	2	6.00	12.00
Conveyor operators	2	5.00	10.00
Stope bosses	6	5.50	33.00
Motormen	6	5.00	30.00
Motorman helpers	6	4.50	27.00
Nippers	2	4.50	9.00
Timbermen	2	5.00	10.00
Trackmen	2	4.50	9.00
Pipemen	1	5.00	5.00
Pipeman's helper	1	4.50	4.50
Total	130		640.50
Surface labor charged to mining;			
Compressormen	2	5.50	11.00
Blacksmiths	1	6.00	6.00
Drill sharpeners	2	6.00	12.00
Drill-sharpener helpers	2	4.50	9.00
Drill repairman	1	6.00	6.00
Mechanic	1	6.00	6.00
Electrician	1	7.50	7.50
Electrician's helper	1	4.50	4.50
Crushermen	2	5.00	10.00
Tramway gripmen	2	4.50	9.00
Tramway lineman	1	6.00	6.00
Miscellaneous surface labor:			
Truck drivers	2	5.00	10.00
Carpenter	1	6.00	6.00
Roustabouts	4	4.50	18.00
Total	24		121.00

TABLE 5. - Labor for mining 2,000 tons daily from 20-foot bed, including development (Cont'd.)

Classification	No. men per day (2 shifts)	Wage scale per shift (Jan. 1931)	Amount per day
Supervision:			
Superintendent	1/2	$27.80	$13.90
Mine foreman	1	8.00	8.00
Tramway foreman	1	8.00	8.00
Shift bosses	4	7.00	28.00
Chief engineer	1	8.00	8.00
Assistant engineer	1	6.00	6.00
Chainman	1	4.50	4.50
Clerk-purchasing agent	1/2	8.00	4.00
Timekeeper	1	5.00	5.00
Warehouseman	1	8.00	8.00
Warehouse helper	1	4.50	4.50
Total	13		97.90
Grand total	167		859.40

Shift per ton	0.0835
Tons per shift	12.0
Labor and supervision per ton.	.430
Plus $0.020 per ton for workmen's compensation	.020
Total operating labor cost per ton	.450

Electrician, $225 per month.
Superintendent, $10,000 per year.
Foremen, $240 per month.
Shift bosses, $210 per month.
Engineer, $240 per month.
Assistant engineer, $180 per month.
Clerk-purchasing agent, $240 per month.
Timekeeper, $150 per month.
Warehouseman, $240 per month.

Supervision. - The supervisory force listed in table 5; the cost of supervision is $0.049 a ton.

Total labor and scale of wages. - A force of 167 men is contemplated, with a daily pay roll of $859.40 (see table 5).

The wage scale is shown in table 5. This is the scale paid in January 1931 in western Colorado mining districts, from which the labor supply would probably be drawn. The table also shows the total shifts and total labor cost per ton.

Workmen's compensation. - The Colorado rate for 1931 for underground mining was $4.27 per $100 of the mine pay roll. The cost would be $0.02 a ton.

Surface plant. - It is planned to have the camp site in the valley near the retorts and transfer the workmen to the mine by busses. No camp site is near the mine, and excavation must be made in the steep mountainside for all surface structures. A bench will be made at the level of the main entry. On this will be constructed five 20- by 50-foot buildings for shops, warehouses, change rooms, and mine office.

Total plant, interest, and amortization. - Table 6 shows the equipment necessary to mine 2,000 tons of shale a day from the 20-foot-thickness of shale. Most of the prices given are actual quotations furnished in January 1931. In a few instances, as shown, estimates were made. Freight was calculated from the freight tariff in effect in January 1931. Cost of installing equipment was calculated from an estimated price of $0.027 per pound of the machinery for setting it up ready to run.

Total cost of the equipment is $629,346. This would be amortized over 15 years with interest at 6 percent. A total of 10,800,000 tons of shale would be mined during this period. Interest and amortization would be $0.130 a ton.

Cost of supplies. - Table 7 gives the prices of material and supplies used in mining and development.

Summary of costs. - Table 8 is a summary of costs per ton for mining 2,000 tons daily from a 20-foot bed of shale.

TABLE 6. - Capital cost of plant and equipment for mining 2,000 tons daily from 20-foot bed of shale as of January 1931

Underground mining equipment:		
Drilling equipment (delivered at mine from Denver):		
22 drifters, 110-pound, at $335	$ 7,370	
18 jackhammers, 72-pound, at $270	4,860	
16 jackhammers, 40-pound, at $195	3,120	
2 stopers, at $195	390	
Air hose, 3,000 feet of 1-inch at $0.375	1,125	
Air hose, 1,500 feet of 3/4-inch at $0.243	365	
Water hose, 2,000 feet at $0.1545	309	
Drill steel, 20,000 pounds at $0.135	2,700	
22 drill columns, 3-inch, single-screw, complete, at $69	1,518	
Total drilling equipment		$ 21,757
Ore-transportation equipment underground:		
2 trolley locomotives, 8-ton	9,884	
1 trolley locomotive, 4-ton	3,300	
Freight on locomotives, at $3.08 per cwt., Mississippi River points to Grand Junction	1,232	
1 synchronous motor-generator set, 150 kw., 250-volt d. c., 1,200-r.p.m., 3-phase, 60-cycle, 2,200-volt a.c., complete with auto transformer. Shipping weight, 9,100 lbs	3,630	
Freight on motor-generator set, Pittsburgh to Colorado common points, at $1.485 per cwt	135	
1 2-panel, manually operated switchboard, shipping weight 1,600 lb.	850	
Freight on switchboard, Pittsburgh to Colorado common points, at $1.485 per cwt	24	
1 automatic d.c. feeder equipment (300 lb.)	300	
30 cars, 5-ton capacity, Granby-type, weight approximately 8,000 lb., at $650	19,500	
Freight on cars, at $0.70 per cwt., Denver to Grand Junction	1,680	
10 cars, 2-ton, side-dump, weight 3,000 lb., for development work	2,500	
Freight, at $0.70 per cwt	210	
2 conveyors, 36 inches wide, four 300-foot sections each conveyor, each section with 20 hp. motor, complete and installed in mine	30,000	
6 electric, triple-drum scraper hoists (1942 price)	20,034	
6 scrapers, including sheaves and cable, at $210, delivered	1,260	

TABLE 6. - Capital cost of plant and equipment for mining 2,000 tons daily from 20-foot bed of shale as of January 1931 (Cont'd.)

Underground mining equipment: (Cont'd.)		
Ore-transportation equipment underground: (Cont'd.)		
2 loading slides for scraper loading in entries (made at mine)	$ 600	
2 mechanical loaders	18,000	
Total transportation equipment		$113,139
Ventilating equipment:		
1 fan, 47,000 cu. ft. per min., against 1-1/4-inch water gage, delivered at mine	335	
1 blower, positive pressure, for driving initial entry 1,650 cu. ft. per min., at 275 r.p.m., delivered at mine	675	
1 10-hp. motor (to be used successively on both fans), delivered at mine	200	
Installing and housing fan	200	
Total ventilating equipment		1,410
Total cost of underground mining equipment		136,306
Outside plant:		
Compressor plant:		
1 compressor, 5,000 cu. ft. per min. capacity at 5,000 feet altitude, complete with 1,000 hp. synchronous motor, receivers, starting panels, and electric equipment, including 20 days' time of erector	39,000	
Freight on compressor (101,000 lb.), motor, and auxiliary equipment (25,000 lb.) at $1.485 per cwt., Pittsburgh to Colorado common points	1,870	
Installation of compressor plant	4,000	
Total of main plant (exclusive of trucking)		44,870
1 compressor, 450 cu. ft. per min. capacity, complete for driving main entry	2,683	
Freight on compressor, weight 7,000 lb.	70	
1 motor, 75-hp., 900-r.p.m. (weight, 3,700 lb.), for driving compressor, delivered	744	
Installation of compressor and motor, at 2-3/4 cents per lb	294	
Total of development compressor plant		3,796
Total cost of compressor plant		48,666
Shop equipment:		
2 sharpeners for drill steel, at $1,000	2,000	
Installation and freight	250	

TABLE 6. - Capital cost of plant and equipment for mining 2,000 tons daily from 20-foot bed of shale as of January 1931 (Cont'd.)

Outside plant: (Cont'd.)		
Shop equipment: (Cont'd.)		
Accessories for sharpeners (dies, dollies, formers, punches, etc.)	$ 1,400	
2 oil forges, complete with motor and blower, delivered	725	
Installation (2,500 lb.)	70	
2 pedestal grinders (air motor), installed	390	
1 blacksmith forge, complete, installed	150	
Shop tools (electric drill, anvils, etc.)	1,200	
Cut-off saw with 5-hp. motor, complete	150	
Total shop equipment		$ 6,335
3 transformers, 75 kv.-amp. (440-, 220-, and 110-volt), delivered		1,267
5 frame buildings, 20 by 50 feet, for shops, warehouses, etc., including locomotive pit, at $2,000	10,000	
Excavation for buildings, 1,000 cu. yd. at $1.35	1,350	
Office, warehouse, changeroom, engineering equipment, etc.	5,000	
Total mine buildings		16,350
Warehouse stock		5,000
Mine rescue and first-aid equipment		2,500
Surface transportation equipment (one-half charged to treatment plant):		
1 truck, 5-ton		
1 truck, 2-1/2-ton		
1 truck, 1-ton		
2 touring cars		
Total value of cars charged to mine		4,250
Total surface mine equipment		84,368
2 ore bins, steel, 5,000 tons capacity, at $45,000	90,000	
Excavation for bins	2,500	
Total cost of ore bins (exclsuive of trucking)		92,500
Crushing plant:		
1 jaw crusher, 36 by 42 inches (run-of-mine to 8 inches)	15,000	
Freight on crusher, 118,000 lb. at $1.145 per cwt., Milwaukee to Colorado common points	1,351	
Motor, 100-hp., 600-r.p.m., weight 6,310 lb., delivered	1,557	
Tex-rope drive, delivered	777	

TABLE 6. - Capital cost of plant and equipment for mining 2,000 tons daily from 20-foot bed of shale as of January 1931 (Cont'd.)

Outside plant: (Cont'd.)		
Crushing plant: (Cont'd.)		
1 cone crusher, secondary (8 inches to through 2-1/2 inches)	$15,000	
Freight, 85,000 lb. at $1.145 per cwt	973	
Motor, 150 hp., 600 r.p.m., weight 7,270 lb. delivered	1,862	
Tex-rope drive, delivered	952	
1 pan conveyor from coarse crusher, 20 feet long, 42 inches wide, steel aprons, speed 52 feet per minute, 7-1/2-hp. motor, weight 20,000 lb., complete	2,200	
1 belt conveyor to ore bins, 40 feet long, 30 inches wide, with frame and rollers; and 1 40-foot belt conveyor with speed reducer and 3-hp. motor, Timken bearings, belt 5-ply, 28-ounce duck with 3/16-inch covers, weight, 13,000 lb., complete	1,700	
Freight on both conveyors at $1.145 per cwt	378	
1 crane, 12-ton, electric, hand-operated, with 16-ton chain block; weight, 5,670 lb.	1,927	
Freight, at $1.145 per cwt	65	
2 beams for crane, 25 feet long, 20 inches deep, 100 lb. per foot, including freight	250	
Installing crane	283	
Foundations at $20 per cubic yard	2,400	
Installation of 2 crushers and motors at 2-3/4 cents per lb	5,955	
Installation of 2 conveyors at 2-3/4 cents per lb	900	
Total crushing plant		$ 58,530
Total cost outside mining plant		235,397
Expenditures required by location of mine:		
Aerial tramway, 2 miles long, all-steel, complete, constructed with terminals (exclusive of bins), 2,000 tons per 8 hours		200,000
Road, 12-foot roadbed, maximum 7 percent grade, 6-1/2 miles long:		
4 miles (300 cu. yd. excavation per 100 ft.) 63,360 cu. yds		
22 miles (100 cu. yd. excavation per 100 ft.) 10,560 cu. yd		
Total, 73,920 cu. yd. at $0.50 per cu. yd	36,960	
20 culverts, 18 feet long, 18-inch diameter, at $2.25 per foot	810	
Total cost of road		37,770

TABLE 6. - Capital cost of plant and equipment for mining 2,000 tons daily from 20-foot bed of shale as of January 1931 (Cont'd.)

Expenditures required by location of mine: (Cont'd.)		
Water system:		
Pump, 35 gal. per min. against 3,000-foot head with 30-hp. motor, Tex-rope drive; weight, pump, 6,800 lb.; motor, 1,400 lb.; drive, 200 lb.:		
Pump	$ 2,100	
Motor	320	
Drive	110	
Freight	370	
Installation at 2-3/4 cents per lb	231	
Tank, 15,000 gal. capacity, installed	500	
Pipe line, 3-inch, 15,000 feet (estimated), at $34.233 per 100 ft., delivered at Grand Junction	5,135	
40 expansion couples at $2.65	106	
Installing pipe line (on surface)	1,000	
Total cost of water system		$ 9,872
Trucking initial equipment from railroad to mine at $20 per ton		10,000
Total		257,642
Grand total		629,346

TABLE 7. - Prices of supplies included in cost per foot of development and cost per ton of ore (as of January 1931)[1/]

Pipe, at Grand Junction:	
8-inch main air line, per 100 feet (4,500 feet)	$119.00
6-inch panel entry air lines, per 100 feet	91.392
3-inch stope air lines, per 100 feet	34.233
2-inch main water line, per 100 feet (5,000 feet)	16.557
1-1/2-inch panel-entry water lines, per 100 feet	12.306
1/2-inch stope water lines, per 100 feet	4.288
Rails, at Grand Junction:	
40 pounds per yard, for main entry, per ton	55.68
16 pounds per yard, for supply tracks in panel entries, per ton	56.68
Ties, at Grand Junction, 6 by 8 inches by 5 feet long, native timber, per 1,000 board feet	28.00
Timber, at Grand Junction, fir, per 1,000 board feet	32.00
Trolley wire, single 0, 0.3188 pounds per foot, per 100 feet	14.40
Hangars for trolley wire, at Denver, each	2.21
Ventilation pipe, at Denver, 16-inch, galvanized, 26-gage, per 100 feet	37.00

TABLE 7. - Prices of supplies included in cost per foot of development and cost per ton of ore (as of January 1931)[1] (Cont'd.)

Cable for scrapers, 3/8-inch, per foot	$ .085
Drill steel:	
1-inch, quarter octagon, per pound	.12
Cost, at Grand Junction, including freight at $1.515 per 100 lb., per lb.	.135
Powder, at Grand Junction, 40 percent-strength gelatin, 1-1/8- by 8-inch, per 100 lb.	14.49
Caps, at Denver:	
No. 6, 25 percent discount allowed, list price per 1,000	15.80
No. 7, 25 percent discount allowed, list price per 1,000	21.25
No. 8, 25 percent discount allowed, list price per 1,000	25.00
Fuse, at Denver:	
Common, 25 percent plus 2-1/2 percent discount allowed, list price per 1,000 feet	7.15
Waterproof, 25 percent plus 2-1/2 percent discount allowed, list price per 1,000 feet	7.50
Power, per month	4.05
Carbide, at Grand Junction, per 100 lb.	8.00
Track spikes:	
3/8 by 3-1/2 inches, per 100 lb.	4.785
1/2 by 5 inches, per 100 lb.	4.135
Fish plates, at Grand Junction:	
For 40-lb. rails, per 100 lb.	4.235
For 16-lb. rails, per 100 lb.	4.985
Bolts, at Grand Junction:	
For 40-lb. rails, 3 by 25/32 inches, per 100 lb.	5.185
For 16-lb. rails, 1-3/4 by 1/2 inches, per 100 lb.	6.435
Nails, at Denver, per 100 lb.	3.25
Shovels, at Denver, round point, per dozen	21.60
Picks, at Denver, 4-1/2-lb., per dozen	10.50
Hammers, at Denver:	
10-lb. each	1.53
3-1/2-lb., each	.85
Timber saws, at Denver, 3-foot, each	2.66
Timbermen's axes, at Denver, 3-1/2-lb., per dozen	16.80

1/ The mine pay roll and plant include labor and trucks for freighting supplies to the mine. However, a charge of $20 a ton is added to the above figures for freighting the material for the mine plant and for the original development work from the railroad to the mine. At the start of operations it is assumed that a freight rate not to exceed the tariff to Grand Junction which is to the westward, would be established to Rulison from eastern points.

TABLE 8. - Summary of costs per ton for mining 2,000 tons daily from 20-foot bed of shale

	Labor	Supervision	Drills and steel	Power	Explosives	Other supplies	Total
Development:							
Panel entries........	$0.014	$0.001	$0.003	$0.004	$0.012	$0.008	$0.042
Ventilation drifts.....	.005	.000	.001	.003	.004	.003	.016
Room necks............	.010	.001	.002	.003	.009	.007	.032
Total development.....	.029	.002	.006	.010	.025	.018	.090
Stoping...............	1/ 166	1/.021	.030	.057	.106	.020	.400
Transportation:							
Scraping..............	.063	.007	-	.018	-	.030	.118
Conveying.............	.005	.001	-	.011	-	.004	.021
Haulage...............	.029	.004	-	.011	-	.011	.055
Total transportation..	.097	.012	-	.040	-	.045	.194
General underground....	.019	.002	-	-	-	-	.021
Surface expense applicable to underground...	.031	.004	-	-	-	.005	.040
Total underground.....	.342	.041	.036	.107	.131	.088	.745
Coarse crushing........	.005	.001	-	.006	-	.019	.031
Tramway...............	.008	.005	-	.006	-	.014	.033
Miscellaneous surface...	.017	.002	-	2/.005	-	-	.024
Total surface.........	.030	.008	-	.017	-	.033	.088
Workmen's compensation..	.020	3/	-	-	-	-	.020
Total underground and surface...............	.392	.049	.036	.124	.131	.121	.853
Deferred development:							
Main entry............	.006	3/	.001	.001	.002	.004	.014
Ventilation raise......	.001	3/	.000	.000	.000	.000	.001
Ventilation drift......	.003	3/	.000	.000	.001	.002	.006
Total................	.010	3/	.001	.001	.003	.006	.021
Interest and amortization	-	-	-	-	-	.130	.130
Grand Total..........	.402	.049	.037	.0125	.134	.257	1.004

1/ Stope bosses charged as labor, not supervision.
2/ Pumping, lighting, and miscellaneous power.
3/ Included under labor.

Mining 4,000 Tons Daily from 20-Foot Bed

Four thousand tons daily could be mined from the 20-foot bed by working more places. About 2 cents a ton could be saved in interest and amortization, about 1/2 cent in supervision, 1/2 cent in tramming, and 1 cent in mining and transportation, a total saving of 4 cents a ton, which would make the total mining cost about $0.96 per ton.

Mining 5,000 Tons Daily from 44-Foot Bed

The general system described above for mining the 20-foot thickness could be used in mining the 44-foot shale bed. The pillars between rooms probably would need to be wider because of their greater height; therefore, it is proposed to lay out 30-foot rooms and 30-foot pillars. If experience shows that this width is greater than required, it could be reduced, with corresponding reduction in development costs.

To avoid exceeding a length of 1,200 feet for the panel conveyor, only 20 rooms would be opened on each side of a panel. The panel entry then would be 1,270 feet long from main entry to ventilation drift. As before, 360 feet of ventilation drift would be required for each panel.

As in the previous lay-out, a block would consist of 20 panels, 10 on each side of the main entry. This block would be developed as usual - that is, 4,100 feet of main entry, 1,080 feet of ventilation drift, and 400 feet of ventilation raise.

Because approximately 1,500 tons of shale would have to be left in place around the neck of each room to protect the panel entry, 11,300 tons would be mined from a room rather than 12,800 tons, which would be the content of a full block of shale 30 by 44 by 150 feet in size. A panel of 40 rooms would produce 452,000 tons. The panel entry, 8 by 10 feet in cross section and 1,210 feet in length, would add 6,250 tons to the production from a panel; and the 360 feet of ventilation drift, 8 by 8 feet in section, would add 1,500 tons, making the total production from a panel 460,000 tons. At the assumed production rate of 5,000 tons per day, this would constitute 92 days' supply. Production from a block of 20 panels would be 9,200,000 tons, or enough for 5.3 years.

Development

Because of the greater height of shale mined, development charges would be only about half those in the 20-foot bed, in spite of the greater width of pillars.

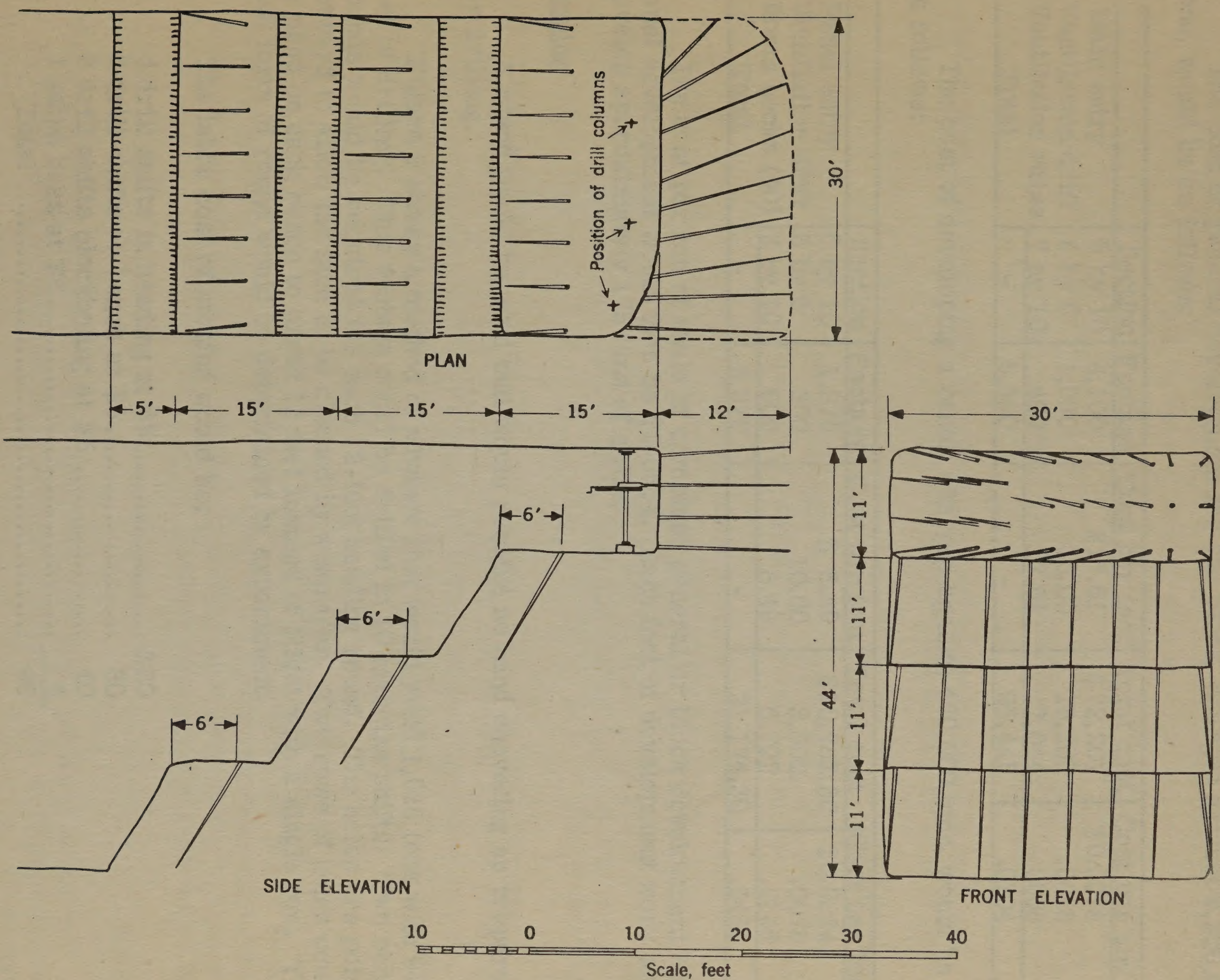

Figure 9.—Method of drilling in room for mining 44-foot bed of shale.

The cost of general development for one block, charged against 9,200,000 tons, would be as follows:

	Section	Footage	Cost per foot	Total cost	Cost per ton
Main entry	8 by 10	4,100	$17.61	$72,201	$0.0078
Ventilation drift	8 by 8	1,080	15.00	16,200	.0018
Ventilation raise	7 by 10	400	17.61	7,044	.0008
Total	-	5,580	-	95,445	.0104

The cost of developing a panel, charged against 460,000 tons, would be as follows:

	Section	Footage	Cost per foot	Total cost	Cost per ton
Panel entry	8 by 10	1,270	$ 8.49	$10,782.30	$0.0234
Ventilation drift	8 by 8	360	10.00	3,600.	.0078
Room necks (40)	8 by 10	800	8.49	6,792	.0148
Total	-	2,370	-	21,174.30	.0460

The cost per ton of shale of combined general or block development and panel development would then be $0.0564. Each foot of development work would develop approximately 175 tons of shale.

Stoping

A round would be used that would require no hand shoveling as preparation for drilling.

Figure 9 shows a method of advance that would yield 1,025 tons with 940 feet of drilling. This footage could be drilled in 10 machine shifts. Two bench rounds would be required for each 12-foot heading round. The holes are pointed outward to allow the face to be cleaned by a scraper. Two rows of holes could be used on each bench to break 12 feet instead of 6 feet with a single row. The best form of round would be determined by experiment.

The labor cost of stoping would be:

4 drill shifts in heading at $5	$20
6 drill shifts on bench at $5	30
8 drill shifts blockholing at $5	40
1 stope boss at $6	6
Total	96

The labor cost would be $0.094 a ton; adding 20 percent for contingencies, the cost would be $0.11

Owing to the higher bench, less explosives per ton would be required than in the 20-foot bed; allowing 1/2 pound a ton, the cost of explosives would be 8 cents. As less footage would be drilled per ton of ore broken, the power requirement also would be less. Two 5,000-cubic feet-per-minute compressors with 1,000-horsepower motors are provided, and the entire cost of air compression is charged to stoping. The cost per ton of shale would be

$$\frac{2{,}000 \times 4.04 \text{ (cost per hp. per month)}}{5{,}000 \times 30} = \$0.054.$$

The cost of supplies other than explosives is estimated as 4 cents a ton. The total cost of stoping would be 29 cents a ton.

Transportation

Scraping and conveying. - More than double the tonnage would be handled per shift in each panel than in mining the 20-foot bed.

The cost of scraping would be materially less than in the 20-foot bed because of the greater amounts of shale broken in each round in the stopes. It is estimated that a scraper crew could load out slightly more than 200 tons a shift. The charge for labor on the conveyors per shift would be the same in both cases, which would reduce the labor cost per ton by half, or to 1/4 cent in the 44-foot bed.

Locomotive haulage. - The charge for haulage in cars probably would be the same as for the 20-foot bed, which has been calculated as 5 cents a ton. The use of a conveyor instead of cars in the main entry would have the advantage that the shale, as it came from the mine, could be discharged directly into the hopper of the primary crusher in a steady stream. In mining by the advancing system, the length of the haul in the main entry would be relatively short for the first few years. Under these conditions, the charge for conveying should be less than half that of transporting the shale in cars. The main disadvantage would be that if the conveyor broke down, the whole mine would be tied up. As the main-line conveyor would be in place for many years, it should be substantial enough to reduce the possibilities of delays. Under this system, supplies would be brought into the mine through the ventilation drifts.

Crushing

The same crushing plant would be used as for crushing 2,000 tons a day but would have to be run 20 hours a day, which would require three shifts of operators.

The labor cost would be $\frac{6 \times \$5}{5{,}000}$ or \$0.006 a ton.

Supplies and repairs are estimated at 1.9 cents a ton.

Power would be the same as before, $0.006 a ton. Total cost would be 3.1 cents a ton.

Aerial Tramway

The aerial tramway having a capacity of 2,000 tons in 8 hours will be run 20 hours a day, giving 4 hours leeway. Carstarphen has estimated the cost of transporting the shale on the tramway as 2 cents a ton.

General and Surface Labor

The cost per ton of general underground labor and of surface labor chargeable to mining is approximately the same as for the 20-foot bed - 1.9 and 2.5 cents, respectively. Miscellaneous surface labor has been estimated at $0.012 a ton.

Supervision

The supervisory force for mining 5,000 tons daily from the 44-foot bed would be increased over that estimated for mining the 20-foot bed by the addition of a superintendent at $500 a month and by using the full time of a clerk instead of half time. Cost of supervision would still be considerably less than before and would amount to 2.3 cents a ton.

Total Labor and Scale of Wages

Table 9 is an estimate of the total daily pay roll for mining 5,000 tons a day from shale 44 feet thick. The table also shows the cost per ton, shifts per ton, and scale of wages.

TABLE 9. - Labor for mining 5,000 tons a day from shale 44 feet thick, including development

Class of labor	No. of men per day (2 shifts)	Wage scale per shift (January) 1931	Amount per day	Cost per ton
Underground:				
Development:				
Miners..........................	14	$5.00	$ 70.00	
Miners' helpers	7	4.50	31.50	
Loader operators	7	5.00	35.00	
Loader operator's helpers	7	4.50	31.50	
Total	35		168.00	$0.034

TABLE 9. - Labor for mining 5,000 tons a day from shale 44 feet thick, including development (Cont'd.)

Class of labor	No. of men per day (2 shifts)	Wage scale per shift (January) 1931	Amount per day	Cost per ton
Underground: (Cont'd.)				
Stoping:				
Miners	100	$5.00	500.00	
Stope bosses	6	5.50	33.00	
Total	106		533.00	$0.107
Transportation:				
Scraping:				
Scraper hoistmen	24	5.00	120.00	
Scraper hoistman's helpers	24	4.50	108.00	
Scraper bosses	4	6.00	24.00	
Total	52		252.00	.050
Conveying:				
Conveyor operators	2	5.00	10.00	.002
Haulage:				
Motormen	14	5.00	70.00	
Motorman's helpers	14	4.50	63.00	
Total	28		113.00	.023
Total transportation	82		375.00	.075
General underground:				
Nippers	6	4.50	27.00	
Timbermen	8	5.00	40.00	
Trackmen	2	4.50	9.00	
Pipemen	2	5.00	10.00	
Pipeman's helpers	2	4.50	9.00	
Total	22		95.00	.019
Surface labor charged to underground:				
Compressormen	2	5.50	11.00	
Blacksmiths	3	6.00	18.00	
Drill sharpeners	4	6.00	24.00	
Drill sharpener's helpers	4	4.50	18.00	
Drill repairmen	2	6.00	12.00	
Mechanics	3	6.00	18.00	
Electricians	2	7.50	15.00	
Electrician's helpers	2	4.50	9.00	
Total	22		125.00	.025
Total underground mining	267		1,296.00	.259

TABLE 9. - Labor for mining 5,000 tons a day from shale 44 feet thick, including development (Cont'd.)

Class of labor	No. of men per days (2 shifts)	Wage scale per shift (January) 1931	Amount per day	Cost per ton
Surface:				
Coarse crushing:				
Crushermen	6	$ 5.00	$ 30.00	$0.006
Tramway:				
Gripmen	6	4.50	27.00	
Linemen	3	6.00	18.00	
Total	9		45.00	.009
Miscellaneous surface:				
Carpenter	1	6.00	6.00	
Truck drivers	2	5.00	10.00	
Roustabouts	6	4.50	27.00	
Total	9		43.00	.009
Total surface	24		118.00	.024
Total labor	291		1,414.00	.283
Supervision:				
Manager	1/2	27.80	13.90	
Superintendent	1	16.67	16.67	
Mine foreman	1	8.00	8.00	
Tramway foreman	1	8.00	8.00	
Shift bosses	4	7.00	28.00	
Chief engineer	1	8.00	8.00	
Assistant engineer	1	6.00	6.00	
Chainman	1	4.50	4.50	
Clerk-purchasing agent	1	8.00	8.00	
Timekeeper	1	5.00	5.00	
Warehouseman	1	8.00	8.00	
Total	13-1/2		114.67	.023
Total labor and supervision	304-1/2		1,528.67	.306
Cost of workman's compensation at $4.27 per $100			65.27	.013
Total labor and supervision cost, including workman's compensation			1,593.94	.319

Shift per ton	0.06
Tons per shift:	
Underground labor	18.7
Surface labor	208.3
Total labor	17.2
Supervision	370.4
Total labor and supervision	16.4

Workmen's Compensation

As a larger tonnage per man employed would be obtained than in the 20-foot bed, the cost of workmen's compensation insurance would be less. It is estimated at 1.3 cents a ton under existing Colorado rates (1931).

Total Plant, Interest, and Amortization

The plant described for mining the 20-foot shale bed with additions would serve equally well for mining the 44-foot bed. Following is a list of the most important additional equipment needed and the total cost of the plant.

Scraping:	
6 additional scraper hoists	$20,034
6 additional scrapers	1,260
Haulage:	
3 additional 8-ton locomotives, and 1 additional 4-ton locomotive, delivered	20,000
40 5-ton cars, delivered	30,000
Compressor plant:	
1 additional 5,000-cubic foot compressor, installed	46,000
Ore bins:	
2 additional 5,000-ton bins, erected	92,000
	209,294
Plus 20 percent for miscellaneous items	41,859
Total increase in capital cost	251,153
Cost of smaller plant	630,000
Estimated cost of larger plant	881,153

This cost would be amortized over a period of 15 years with interest at 6 percent. During that time 27,000,000 tons of shale would be mined. Interest and amortization would average $0.073 a ton.

Summary of Costs

Table 10 is a summary of costs.

Mining 106-Foot Shale Bed

Open stopes are not considered practical for mining the 106-foot shale bed, because shale pillars of this height probably are not strong enough to stand without sloughing. Moreover, the back would have to stand much longer than in rooms in the 20- or 44-foot beds, and the hazard of slabs falling on the workmen would be correspondingly greater.

The choice of mining methods, therefore, lies between shrinkage stoping, sublevel stoping, and a caving method. The costs per ton in shrinkage stoping,

TABLE 10. - Summary of cost per ton of mining 5,000 tons daily from 44-foot bed (Twelve 45-hp. electric hoists at $4.05 per horsepower-month)

	Labor	Supervision	Drills and steel	Power	Explosives	Other supplies	Total
Development[1/]	$0.016	$0.001	$0.003	$0.002	$0.014	$0.010	$0.046
Stoping................	2/.107	2/.011	.025	.054	.080	.015	.292
Transportation:							
Scraping.............	.050	.005	-	.015	-	.030	.100
Conveying............	.002	-	-	.011	-	.004	.017
Haulage..............	.023	.001	-	.011	-	.011	.046
Total...............	.075	.006	-	.037	-	.045	.163
General Underground.....	.019	.001	-	-	-	-	.020
Surface expense charged to underground.........	.025	.002	-	-	-	.005	.032
Total underground.......	.242	.021	.028	.093	.094	.075	.553
Surface operations:							
Coarse crushing......	.006	-	-	.006	-	.019	.031
Tramway..............	.009	.001	-	.006	-	.004	.020
Miscellaneous surface.	.009	.001	-	3/.002	-	-	.012
Total...............	.024	.002	-	.014	-	.023	.063
Workmen's compensation..	.013	4/	-	-	-	-	.013
Deferred development[5/]..	.006	-	-	-	.002	.002	.010
Interest and amortization	-	-	-	-	-	.073	.073
Grand Total....	.285	.023	.028	.107	.096	.173	.712

1/ Includes panel entries, room necks, and ventilation.
2/ Stopes bosses are charged as labor, not supervision.
3/ Includes power for lighting, pumping, and shops.
4/ Included under labor.
5/ Includes main entry, ventilation raise, and part of the ventilation drifts.

as obtained elsewhere, are too high to make this method practical with this grade of material. The main objection to sublevel stoping is that the walls might not hold, therefore, a method of caving generally following standard practice but adapted to the conditions expected at Rulison is proposed.

From inspection of the shale at Rulison, both at the surface and underground in the stopes that were opened during the experimental operations of 1925-27 and 1928-29 and from a study of the action of difficult-breaking rock in mines using the caving method of mining, it is concluded that the oil shale could be mined by a caving method. As this particular rock has never been mined by caving, an experimental stope should be undercut and enough of the shale drawn to determine what the caving action would be before large-scale operations are begun. It would probably be necessary to modify any system devised.

As the shale is a strong, tough rock and is free from faulting or fracturing, development workings probably would not need to be timbered except when weight from the undercutting level is transmitted downward through an unbroken pillar or under the fulcrum of a cantilever of under-cut shale. Such transmission of weight usually can be avoided by properly undercutting and drawing.

As no pillars would be left between panels, a high percentage of the shale in the blocked-out area would be extracted by the caving method.

The deposit is not thick enough to get the lowest costs by a caving method. Except for the cut-off stopes around caving blocks, the cost of development and stope preparation would be the same for a 106-foot bed as it would for one 200 or 300 feet thick. The main disadvantage, of a caving method, however, would be dilution of an already low-grade shale with material of very much lower grade, the average oil content of the 25 feet of overlying shale being estimated at about 10 gallons to the ton. The first 4 feet is almost barren. Assuming a 10-percent dilution, all coming from the 10-gallon beds, the average grade of shale produced by caving would be 23.8 instead of 25.4 gallons a ton.

As large fragments are to be expected in mining, provision must be made for handling them. The methods proposed for mining the 20- and 44-foot beds are such that the shale is not shoveled or passed through gates or chutes. In a standard branch-raise caving method the rock must be pulled first through the draw points, then passed through a grizzly into a gathering raise, and finally drawn from the chute into a car. A modification of the standard branch-raise practice, however, is to draw the shale into scraper drifts, which also are used as bulldozing chambers. Both methods are discussed in this paper.

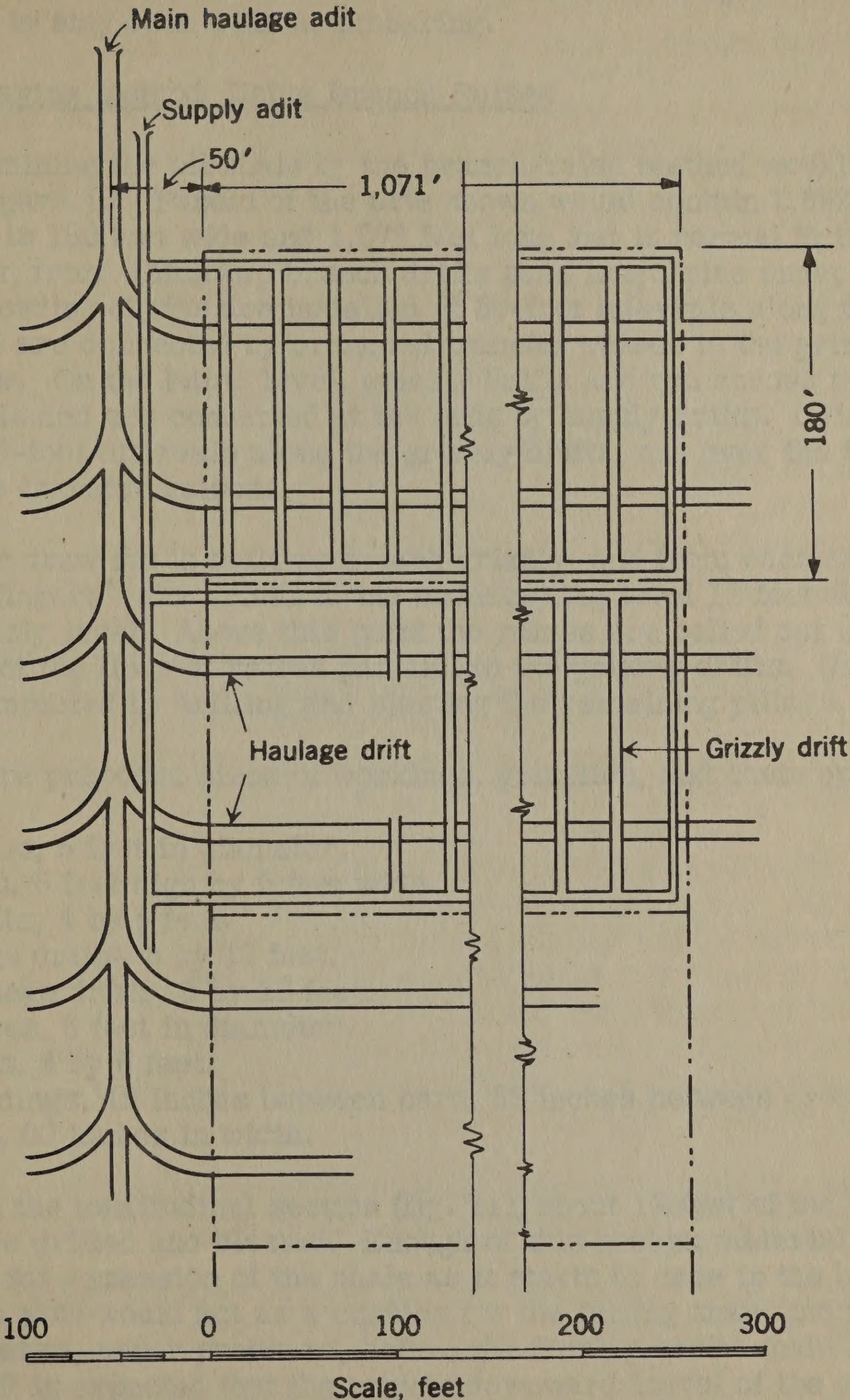

Figure 10.—Lay-out of blocks for mining 106-foot bed of shale.

To prevent the shale from collecting at control points, all openings must be as large as practicable. Although draw points and branch raises are usually 4 by 4 feet in section, these openings should be at least 6 feet in diameter for mining oil shale. The nature of the shale is such that these larger openings could be expected to stay open without timbering.

Undercut Block-caving Method, Using Branch Raises

Blocks for mining the oil shale by the branch-raise method would be laid out as shown in figure 10. Panels of the size shown would contain 1,362,000 tons. Each panel is 180 feet wide and 1,071 feet long and is normal to the main haulage drift, from which two branch drifts pass lengthwise under each panel (fig. 11). Loading chutes are installed at 30-foot intervals along the haulage drifts and are connected by branched transfer raises to the grizzly level 62 feet above. On the latter level, grizzly drifts are run across the panel at 30-foot intervals and are connected at the ends by supply drifts. Grizzlies are installed at 15-foot intervals along the grizzly drifts, one over the top of each branch of the transfer raises.

A control or draw set is built over each grizzly, and from each set two draw raises or "fingers" are driven to the undercutting level 12 feet above the top of the grizzly level. Above this point the raises are belled out in such a way as to connect the lines of raises parallel to the grizzly drifts. Undercutting is then completed by drilling and blasting the remaining pillars.

Following are proposed sizes of workings, grizzlies, and chute openings:

Finger raises, 6 feet in diameter.
Grizzly sets, 6 feet high by 5 feet wide.
Grizzly drifts, 4 by 5 feet.
Main haulage drifts, 8 by 13 feet.
Branch haulage drifts, 8 by 10 feet.
Branch raises, 6 feet in diameter.
Supply drifts, 4 by 6 feet.
Grizzly openings, 16 inches between bars, 36 inches between cross pieces.
Chute gates, 60 inches in width.

As shown in the longitudinal section (fig. 11), about 12 feet of the bottom of the block will be drilled and blasted. Enough of this broken material would be drawn to allow for expansion of the shale as it starts to cave in the back. This blasted shale also would act as a cushion for the falling shale and allow some travel downward, under pressure, before the freshly caved shale reached the draw points. It is expected that the uneven downward travel of the caved shale would tend to shatter flat slabs. Possibly a thickness greater than 12 feet would have to be mined in the undercutting operation to allow better breaking up of the caving shale before it reached the draw points.

The work would be organized so that one operation would not interfere with another. Undercutting would precede drawing far enough so that the undercut area would take weight before the last pillar between the connected rows of raises was blasted.

It is purposed to mine the shale by advancing from one end to the other of a continuous panel rather than in blocks, so that the flat beds may form cantilevers and be put under a strain before caving, and thus tend to prevent the shale from breaking into large slabs.

The panel would be cut off at the ends and sides by narrow shrinkage stopes from the undercut level to the top of the shale. After the first panel was mined, only the end and one side cut-off would be necessary, and probably it would not be necessary to run these stopes to the top of the shale. The desirable height could be determined only by experience. If any large section of a panel should fail to cave, it could be cut off by running shrinkage stopes across the panel wherever needed. The 180-foot width of panel, which is more than customary in the mining of porphyry copper ores, was taken to insure caving of the shale without extending the undercutting an excessive distance along the panel.

Development work in panels. - To prevent interference with haulage of the shale, supplies would be brought into the mine through a service adit at the grizzly level. All development work on the grizzly level and above would be done through this drift, which also would be used for the return air circuit in the ventilation system.

The main haulage drifts would be in a bed that carries more oil than the average stope. The material broken on the haulage level could be sent to the retorts. The first 40 feet of the branch raises would be in shale carrying 15 to 20 gallons a ton, which also probably could be retorted. The upper 20 feet of the branch raises, the grizzly drifts, and most of the draw raises would be in nearly barren shale. It is probable, however, that it would be more economical to send all the shale from development work to the retorts rather than to keep it separate and put it over the dump.

Haulage drifts. - The main haulage drifts would be 8 by 13 feet to allow for a double track. The drifts under the panels would be 8 by 10 feet in section.

The estimated cost per foot of the haulage drifts is $8.49, the same as proposed for the panel entries in mining the 20-foot bed.

Supply and grizzly drifts. - The supply and grizzly drifts would be run 4 by 6 feet in section. The broken rock either would fall or be shoveled into the branch raises. The estimated cost is as follows:

Cost of driving grizzly drifts (4 by 6 feet in clear)

One 3-foot round per shift; average break, 2.5 feet

	Cost per foot
Labor, 1 shift at $5.00	$2.00
Explosive, 6-1/2 lb. per ft. at $0.16	1.04
Fuse and caps	.20
Air	.67
Sharpening steel, 12 bits per round at $0.10 each	.48
Drill repairs at $0.40 per shift	.16
Other supplies	.10
	4.65
Plus 20 percent for contingencies	.93
Total	5.58

Branch raises. - The branch or "finger" raises are to be run 6 feet in diameter. The cost per foot is estimated as follows:

Cost of branch raises (6 feet in diameter)

One round per shift; average advance, 4 feet

	Cost per foot
Labor, 1 shift at $5.00	$1.25
Explosive, 4 lb. at $0.16 per lb.	.64
Fuse and caps	.20
Air	.45
Sharpening steel, 16 bits at $0.10 each	.40
Drill repairs at $0.40 per drill shift	.10
Other supplies	.10
Transportation of broken rock ($0.05 per ton)	.10
	3.24
Plus 20 percent for contingencies	.65
Direct cost per foot	3.89

Cut-off stopes. - The shrinkage cut-off stopes would be run at such a width as to give the lowest cost per foot of area cut off. This is assumed to be 4 feet. The cost per ton of breaking the shale in the shrinkage stopes is estimated as follows:

Labor	$0.31
Explosive, fuse, and caps	.16
Air	.12
Steel sharpening and loss, at $0.10 per bit	.05
Drill repairs	.05
Other supplies	.01
Total	.70

The cut-off area of shrinkage stope necessary for an initial panel would be (2,130 + 360) x 106, or 263,940 square feet. The tons broken would be $\frac{263,940 \times 4}{15}$, or 70,400. Upon the basis of $0.70 a ton, the cost per square foot would be $0.19. A cost of about $0.10 a square foot is being obtained in cut-off stopes in porphyry at an Arizona mine. In succeeding panels, only one side-shrinkage cut-off stope would be required, reducing this operation to 40,000 tons a panel.

Charged against the 1,362,000 tons in a panel, the cost of shrinkage stoping would be $0.036 a ton for an initial stope but only $0.021 for a normal stope with only one side cut-off stope.

Finger raises. - As shown by figure 11, the finger raises extend 12 feet above the top of the grizzly drifts to the elevation at which the shale is undercut. The pillars left by using finger raises of this height should be large enough to protect the grizzly drifts. Experience might show that shorter pillars will prove satisfactory. At a property where limestone is mined by caving, pillars 6 feet high afford enough protection to the grizzly levels so that they stand well without timber. The finger raises would be belled out to permit the boulders to come near enough to the grizzly level to be blockholed without the necessity of men going into the raises to do the work. Shortening the raises would have the same effect.

In general, as the shale increases in strength it is likely to break into larger fragments. Fortunately, however, as the strength of the shale increases, the height of the pillars necessary to protect the grizzly level may be reduced. A balance must be attained between affording protection to the grizzly level and permitting the boulders to come near enough to the level to be blockholed safely.

The cost per foot of driving the finger raises is estimated as being the same as for the branch raises ($3.89).

Undercutting. - As stated, a thickness of 12 feet at the bottom of the shale would be drilled and blasted. The amount thus mined in each panel would be

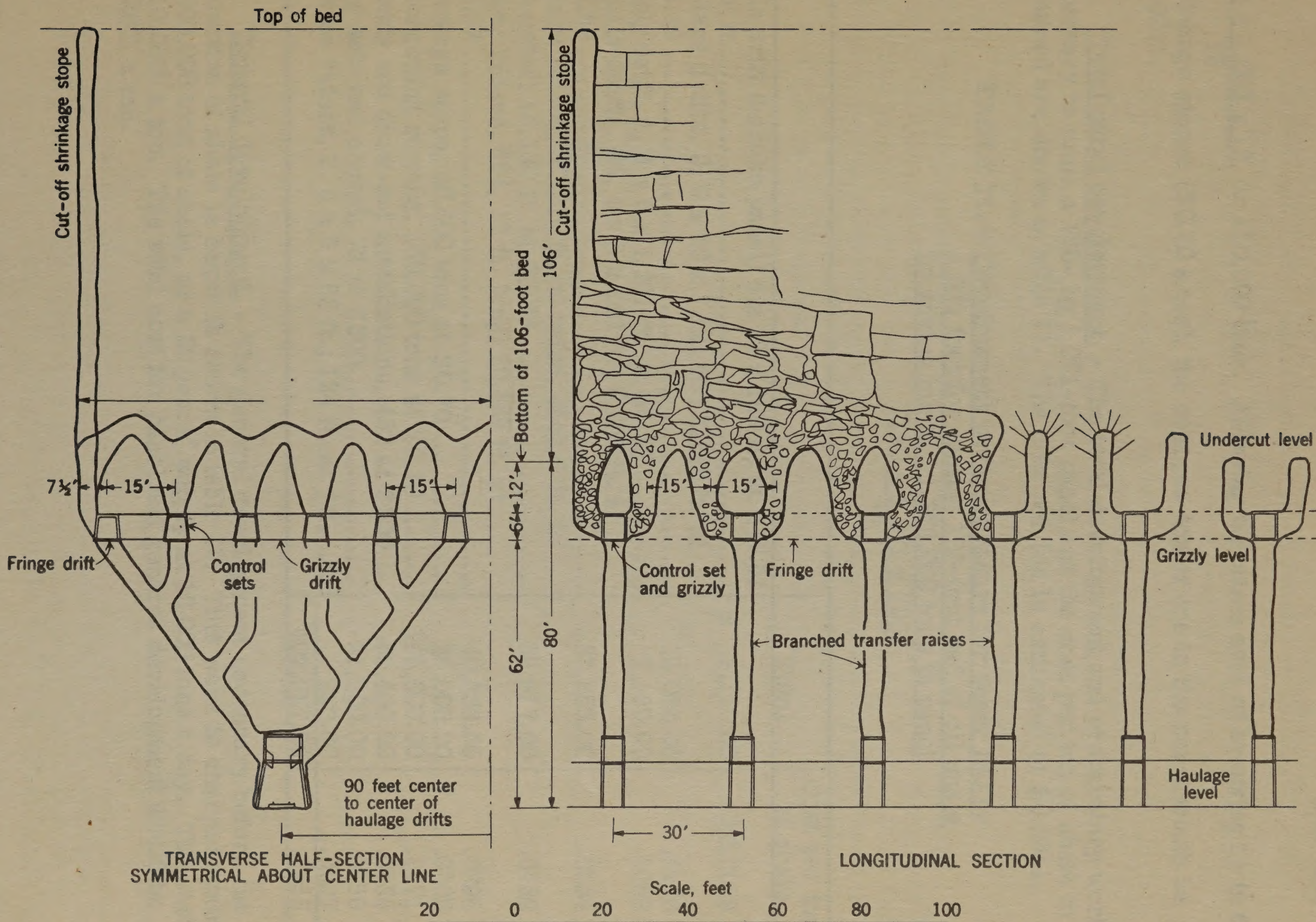

Figure 11.—Underground block-caving method for mining 106-foot bed of shale.

$\frac{176 \times 1{,}063 \times 12}{15}$, or 150,000 tons. Allowing the same cost of breaking as in the shrinkage stopes ($0.70 a ton), the cost per ton of ore in the panel would be $0.0771.

Total panel development. - The total development and preparatory work necessary to mine a 180- by 1,071-foot panel and the cost per ton of shale to be mined are shown in table 11. The cost per ton is estimated at $0.2961.

TABLE 11. - Development work necessary for panel 180 by 1,071 feet for mining 106-foot bed of oil shale by caving method 1,362,000 tons in panel $\left(\frac{180 \times 1{,}071 \times 106}{15}\right)$

	Total	Cost per ton of shale
Main drift (across panel) 8 x 13 x 180 ft. at $17.61 per ft	$ 3,170.00	$0.0023
Haulage drifts, 2, 9 x 10 x 1,121 ft.; 2,242 ft. at $8.49	19,034.00	.0140
Supply drift, 1, 4 x 6 x 1,291 ft. at $5.53	7,139.00	.0052
Grizzly drifts, 36, 4 x 6 x 160 ft.; 5,760 ft. at $5.53	31,853.00	.0234
Branch raises, 72,210 ft. of raise, each 6 ft. in diameter; 15,120 ft. at $3.89	58,817.00	.0432
Finger raises, 864, 12 ft. long; 10,368 ft. at $3.89	40,332.00	.0296
Shrinkage stope, 40,000 tons at $0.70	28,000.00	.0205
Undercutting stoping, 150,000 tons at $0.70	105,000.00	.0771
Grizzly and draw-set installations, 432 at $200 ...	86,400.00	.0634
Pony sets and chutes, 72 at $300........	21,600.00	.0159
Service raises, 2, 4 x 6 x 62 ft.; 124 ft. at $8	992.00	.0007
	402,337.00	.2953

General development. - The general development necessary before the production of shale is begun is shown in table 12. This work is charged against 72,000,000 tons of shale, or a 20 years' supply at 10,000 tons a day. The cost is $0.0008 a ton. The total cost for panel and general development would be $0.2961 a ton.

TABLE 12. - General development necessary for mining block of 72,000,000 tons (20 years' supply)

Main entry, 490 feet at $17.61	$ 8,628.90
Supply drift, 1,121 feet at $8.49	9,517.29
Supply drift, 1,411 feet at $15.00	21,165.00
Ventilation drift, 1,800 feet at $8.49	15,282.00
Total	54,593.19
Cost per ton of shale, general development	0.0008
Cost per ton of shale, panel development	.2953
Total cost development per ton	.2961

Drawing. - To allow for drawing down the shale in the area being worked an average of 1-1/2 feet a day, 22-1/2 tons would need to be pulled from each draw point. For a production of 10,000 tons a day, 444 draw points would have to be in service. The best drawing practice probably would be to have 6 lines of grizzlies with 24 draw points active in each panel. Three or four panels would be under production at a time. If 1 foot a day vertically should be mined in the productive area (equivalent to 15 tons a day per draw point), 4 or 5 panels would have to be active; allowing for finishing one stope and starting another during much of the time, 6 panels would have to be in operation to produce 10,000 tons daily.

After being undercut and caved, the shale would be drawn through the draw points and passed through the grizzlies. Slabs too large to go through the grizzlies would be block-holed and blasted at the bottom of the draw points. The chute tappers would wear safety belts, as is the practice at the Morenci (Ariz.) mine of the Phelps-Dodge Corporation, to prevent falling through the grizzlies.

At Morenci, an average of 120 tons a shift per chute tapper is drawn in hard ore.[16/]

At the Inspiration Copper mine at Inspiration, Ariz., with the same kind of control but in better-breaking ore 250 tons is drawn per chute tapper. On account of the possibly large amount of chute blasting, an average of 100 tons a day has been assumed for mining the oil shale. At $4.50 a day for chute tappers, the labor cost of drawing the ore would be $0.045 a ton.

Dilution. - Judging from the results obtained at copper mines where an undercut caving method is used,[17/] and from the physical characteristics of

16/ Gardner, E. D., Undercut Block-Caving Method of Mining in Western Copper Mines: Bureau of Mines Inf. Cir. 6350, 1930, 44 pp. (p. 28).
17/ Gardner, E. D., Work cited in footnote 16.

the oil shale, a dilution of about 10 percent should be expected in drawing the anticipated tonnage from a panel.

Owing to the absence of vertical soft streaks and sticky material in the shale, most of the dilution probably would come from the first 25 feet above the beds being mined. This being the case, the expected average grade of the shale would be 23.8 gallons a ton.

Transportation. - The cost of hauling the shale is taken at the same figure as in mining the 20- and 44-foot beds ($0.050). The lower haulage costs attendant upon the larger tonnage hauled probably would offset the higher cost of loading the cars through chutes than from a conveyor belt.

General underground expense. - The cost per ton of miscellaneous work underground is difficult to estimate before operations are begun. An approximate figure of 3 cents a ton is used.

At it is expected that the ground will stand better than in copper mines using caving methods, less repair work should be necessary in the haulage and grizzly drifts. More repair work probably would be necessary at grizzlies and in chutes than the average for copper mines. As the mine can be laid out in a regular pattern and temperatures are low, ventilation should cost less.

Surface labor charged to underground operations. - The cost of $0.025 a ton for mining the 44-foot shale bed has been used for surface labor. The proportionate expense of labor for sharpening steel, repairing drills, and operating the compressors is included in the estimated cost of stope preparation and development. This is allowed as an additional safety factor.

Supervision and engineering. - Close control of drawing is necessary with a caving system of mining. This work usually is supervised by the engineering department. An engineer is detailed to each section of the mine and checks the quantity of ore drawn from each chute, to conform to a predetermined rate.

The supervising, engineering, and clerical force necessary to mine 10,000 tons daily is shown in table 13.

Workmen's compensation. - Owing to a larger tonnage per man, a relatively smaller force per ton mined would be required than in mining the thinner shale beds. The charge per ton for workmen's compensation is estimated at $0.01.

Total plant, amortization, and interest. - The equipment necessary to mine 10,000 tons a day is listed in table 14.

TABLE 13. - Monthly pay roll, supervision, engineering, and clerical

Manager, $16,000 a year, 1/2 charged to mine....	$ 667
Superintendent, $10,000 a year........................	833
Foreman, $6,000 a year................................	500
Stoping shift foreman, $4,800 a year	400
Development foreman, $4,800 a year	400
Shift bosses, 6 at $180..................................	1,080
Chief engineer..	500
Stope engineer..	300
Assistant engineers, 8 at $175	1,400
Chairman, 2 at $150......................................	300
Draftsman	200
Safety engineer...	250
Ventilation engineer	250
Chief clerk	300
Time clerks, 4 at $150	600
	7,980

This constitutes a charge of 2.66 cents a ton.

TABLE 14. - Capital cost of plant and equipment for mining 10,000 tons daily from 106-foot bed[1]

Underground mining equipment:		
Drilling equipment:		
30 drifters, 110-lb....................................	$ 10,050	
100 stopers	19,500	
60 jackhammers, 40-lb...................................	11,700	
30 drill columns, 3-in., single-screw	2,070	
Air hose, 1-in., 6,000 ft	2,250	
Air hose, 3/4-in., 7,000 ft	1,700	
Water hose, 10,000 ft...................................	1,540	
Total...		$ 48,810
Underground ore-transportation equipment:		
8 trolley locomotives, 8-ton............................	39,536	
4 trolley locomotives, 4-ton............................	13,200	
Freight on locomotives..................................	4,928	
1 synchronous motor-generator set, 600-kw., 250-volt d.c., 900-r.p.m., 3-phase, 60-cycle, 2,200-volt a.c., complete with auto transformer; shipping weight, 34,700 lb.	11,560	
Freight on motor-generator set..........................	515	
1, 2-panel, manually operated switchboard; shipping weight, 1,800 lb.	1,125	

[1] See footnote p. 52.

TABLE 14. - Capital cost of plant and equipment for mining 10,000 tons daily from 106-foot bed[1] (Cont'd.)

Underground mining equipment: (Cont'd.)		
Underground ore-transportation equipment: (Cont'd.)		
Freight on switchboard	$ 27	
1 automatic d.c. feeder..	300	
120 5-ton Granby-type cars	78,000	
Freight on cars	6,720	
20 2-ton side-dump cars for development work	5,000	
Freight on cars	420	
2 mechanical loaders	18,000	
Total		$179,331
Ventilation equipment:		
2 fans with motors, at $2,500, delivered	5,000	
Installation of fans..	2,500	
4 blowers, positive pressure, at $675	2,700	
4 10-hp. motors, at $200..	800	
Total		11,000
Total underground mining equipment		239,141
Outside plant:		
Mine surface equipment:		
Compressor plant:		
3 5,000-cu.-ft.-per-min. compressors	117,000	
Freight on 3 compressors	5,610	
Installation of compressor plant	12,000	
Total..		134,610
Shop equipment:		
9 sharpeners for drill steel................................	9,000	
Installation and freight..	1,125	
Accessories for 9 sharpeners................................	6,300	
6 oil forges	2,172	
Installation of forges	210	
Blacksmith and repair-shop equipment	10,000	
Total..		28,807
9, 75-kv.-a. transformers		3,798
Buildings and shops		35,000
Excavation for buildings		5,000
Warehouse stock		10,000
Mine rescue and first-aid equipment		2,500
Surface transportation equipment		10,000
Total mine surface equipment		229,715

See footnote p. 52.

TABLE 14. - Capital cost of plant and equipment for mining 10,000 tons daily from 106-foot bed[1/] (Cont'd.)

Outside plant:(Cont'd.)		
Crushing plant: (Cont'd.)		
1 jaw crusher, 54 by 72 in., crushing from run-of-mine to 8 in., capacity 500 tons per hour, with Texrope drive; shipping weight, 350,000 lb.	$ 36,000	
Freight on crusher	4,000	
1 250-hp., 585-r.p.m. motor for crusher, delivered	2,800	
2 cone crushers, 8 in. through 2-1/2 in.	30,000	
Freight on cone crushers	1,946	
2 motors, 150-hp., delivered	3,724	
Texrope drives	1,904	
2 pan conveyors from coarse crusher to cone crushers	4,400	
2 belt conveyors, 40 ft. long, from cone crusher to ore bins	3,400	
Freight on conveyors	756	
1 crane, 12-ton	1,927	
Freight, 5,670 lb. on crane	65	
Beams for crane, including freight	250	
Installing crane	283	
Foundation for crushing plant	4,800	
Installation of 3 crushers and motors	12,000	
Installing 4 conveyors	1,800	
Crusher building, excavation and foundations.........	10,000	
Total..		$120,055
Ore bins:		
Ore bin, 5,000 tons capacity	45,000	
Ore bin, at head of aerial tram, 10,000 tons capacity	90,000	
Excavation for bins	3,750	
Total		$138,750
Total outside plant		488,520
Expenditures required by location of mine:		
Aerial tramway, 2 mi. long		550,000
Road, 12-ft. roadbed, 4 mi. long..........................		37,770
Water system:		
Pump, 70 gal. per min. against 3,000-ft. head, complete, including freight and installation	3,135	
2 15,000-gal. capacity tanks	1,000	
Pipe line, 4-in., 15,000 ft. at .60 cents a ft., delivered	9,000	
40 expansion couples	160	
Installing pipe line	1,500	
Total..		14,795
Trucking initial equipment from railroad to mine		20,000
Total expenses required by location		622,565
Grand total..		1,350,226

1/ Unit prices, except as noted, are those given in the corresponding table of plant cost for mining the 20-foot bed.

The proposed use of a double tramway to handle 10,000 tons a day rather than a railroad to the mine or a haulage adit with a rock raise to the main workings may be questioned. To reach the mine, a rise of 2,500 feet is necessary, with a maximum grade of 2.5 percent, so that a railroad would have to be 10 miles long. At 1 cent per ton-mile, the charge for hauling the shale would be 10 cents a ton, against 2 cents estimated for the tramway. The cost of hauling the shale 2 miles from the bottom of a 2,000-foot rock raise would be as much as the cost of transporting it over a tramway. Pulling the shale from the chutes would increase the cost further. Moreover, the possibility of delays and the danger to workmen should this long raise hold up make this method unattractive.

The total equipment necessary for mining 10,000 tons daily (see table 14) is estimated to cost $1,350,226, or in round figures, $1,400,000. Amortized over 15 years at 6 percent interest, the amount per ton for 72,000,000 tons would be $0.043.

Summary of costs. - The summary of the expected mining costs is shown in table 15.

TABLE 15. - Summary of costs per ton for mining 10,000 tons daily from 106-foot bed of shale

(15 cubic feet = 1 ton)

Drawing, at 100 tons per man = $4.50	$0.045
Development work and stope preparation	.296
General underground expense	.030
Underground transportation	.050
Surface labor charged to underground operations	.025
Supervision, including engineering	.027
Crushing	.030
Tramway	.020
Workmen's compensation	.010
Interest on $1,400,000 at 6 percent, and amortization over 15 years and 72,000,000 tons	.043
Total	.576

Undercut Block-Caving Method, Using Scrapers

In addition to the standard block-caving method as already proposed, an alternate plan is advanced for mining the 106-foot shale bed by using scrapers in the grizzly drifts. These scrapers would pull the broken shale from the

draw points at the bottom of the finger raises along the grizzly drifts and dump it directly into cars in the haulage drifts.

If the shale from the draw points could be drawn by scrapers and loaded directly into cars, no working would be necessary below the grizzly level.

A slightly larger investment would be required for a scraper system than for the standard haulage system. With a branch-raise system, the raises act as measuring devices; whereas, if a scraper system were used, it would be harder to estimate the quantity of shale drawn from each draw point.

The following estimate of mining costs with a scraper system indicates a possible reduction of the total cost from $0.576 to $0.538 per ton, a net saving of $0.038, or 7.1 percent.

As proposed under the section on block-caving using branch raises, preliminary development would be about the same, except that the branch raises would be omitted and the haulage drifts would be immediately below the bull-dozing level instead of 62 feet below it. Panels would contain 1,362,000 tons. These panels are 180 feet wide, 1,071 feet long, and normal to the main haulage drift. A branch haulage drift runs up one side of each panel.

Scraper drifts are driven across the panels from a point about 8 feet above the branch haulage drifts. These scraper drifts are spaced on 30-foot centers and are connected at the ends by fringe drifts, which are used for supplies and ventilation.

At points spaced 15 feet apart in the scraper drifts, two draw or finger raises are driven up to the undercutting level, just as in the standard block-caving method. These raises are belled out as before, and undercutting is completed by drilling and blasting out the intervening pillars.

Panels would be cut off at ends and sides by shrinkage stopes, as for the standard caving method.

Drawing and Scraper System

Figure 12 shows a suggested design for drawing the shale from the finger raises through the grizzly drifts by scrapers into the cars.[18/] A long, wide hopper is built above the haulage level. A double-drum electric scraper hoist

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18/ The Climax Molybdenum Corporation of America uses a similar system at its mine at Climax, Colo. Scraper drifts are also used at the mine of the Consolidated Copper Mines at Kimberly, Nev.

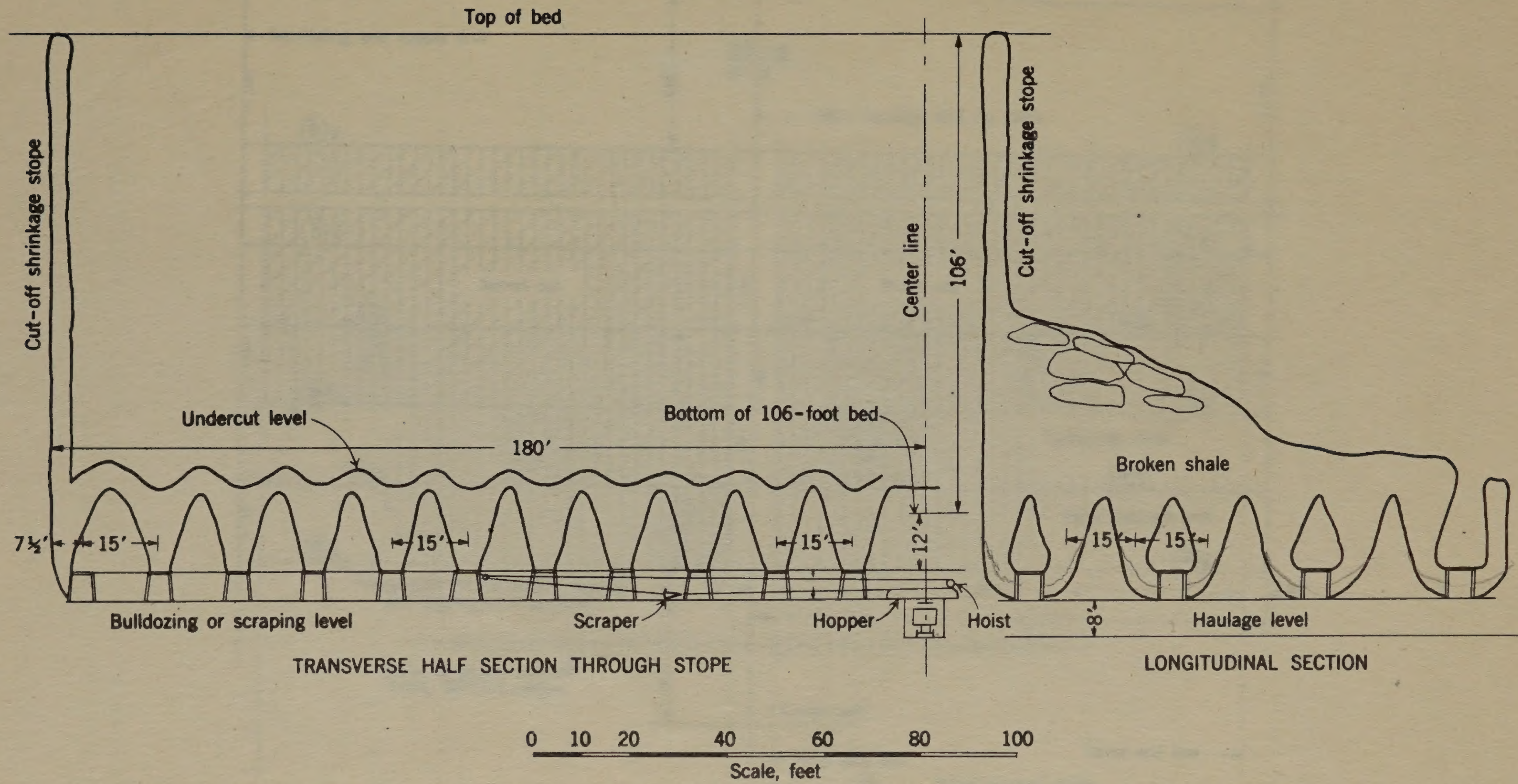

Figure 12.—Undercut block-caving method for mining 106-foot bed of oil shale by using scrapers in bulldozing drifts.

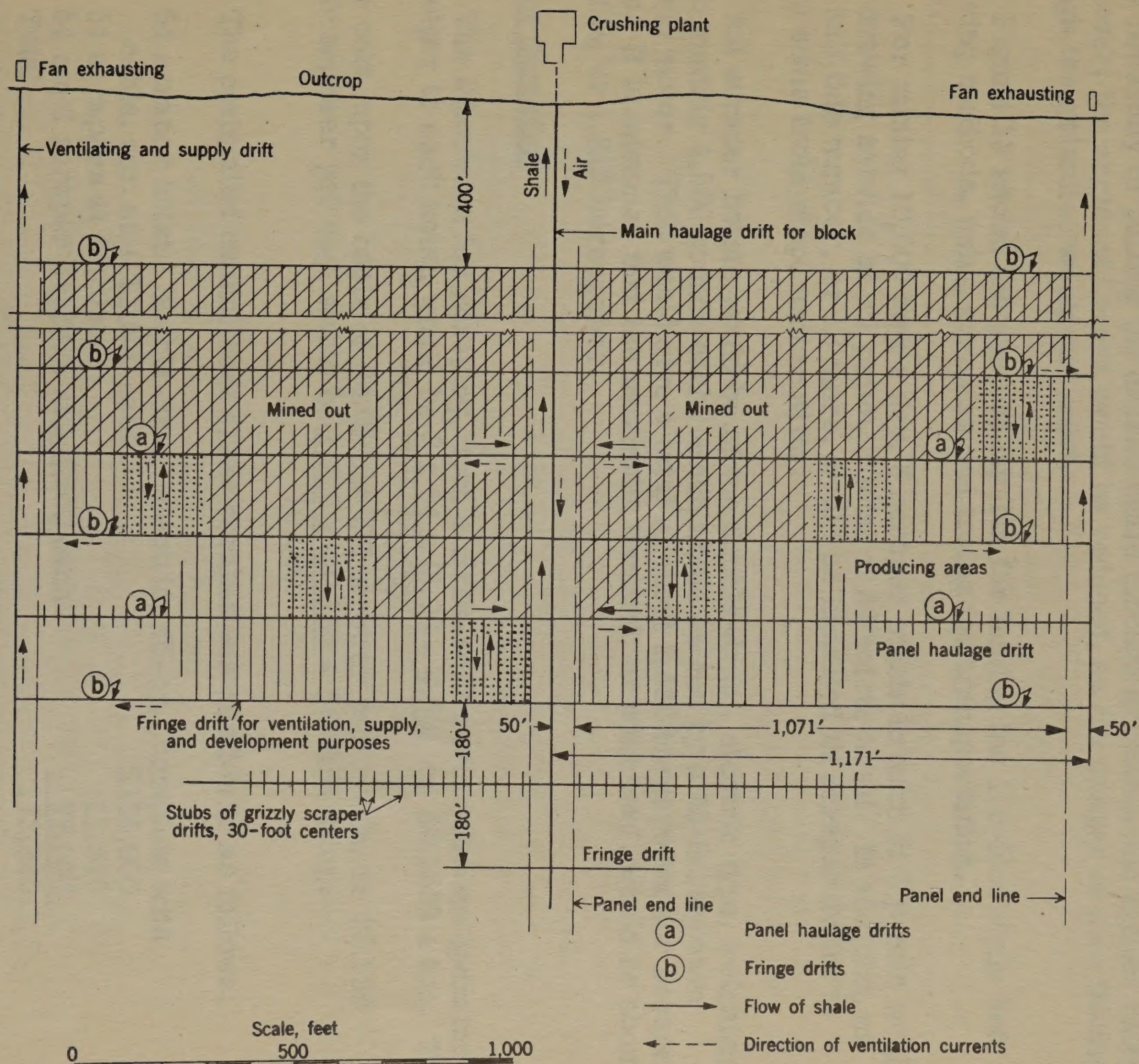

Figure 13.—General lay-out for mining 106-foot shale bed by caving method, using scraper and trains for transportation.

is mounted upon the hopper in such a manner that it may be moved from one end of the hopper to the other within a very short time so that it may be used for scraping from either side of the haulage drift.

The principal advantages of this method of drawing would be in elimination of the necessity of pulling the coarse shale through grizzlies and branch raises. Moreover, the accident hazard would be reduced, as the danger of men falling through the grizzlies would not exist.

Figure 13 shows the general lay-out for mining the 106-foot shale bed by caving methods, using scrapers and trains for transportation.

For mining 10,000 tons a day, 6 scraper hoists in each of 6 panels would be in drawing service at all times, a total of 36 hoists in all. In addition, at least half this number, or 18 more, would be installed in scraper drifts to handle shale from stope undercutting.

All scraper hoists would be of the double-drum, electric type, weighing approximately 4,500 pounds each. Each would be run by a 45-horsepower electric motor. This would give a total of about 2,430 horsepower for scraper hoists. It is assumed that the maximum demand, or peak load, would be about half this, or 1,215 horsepower.

Cost of Scraping

The labor cost for scraping, upon a three-shift basis with one operator and one helper to each hoist, would be $\frac{3 \times 54 \times (5.00 + 4.50)}{10{,}000}$, or \$0.1539 a ton. The power cost, upon the basis of \$4.05 per horsepower per month, or \$0.135 per horsepower per day, would be $\frac{1{,}215 \times \$0.135}{10{,}000} = \$0.0164$ a ton.

The estimated capital cost of the scraper installation is as follows:

54 scraper hoists, double-drum electric, 45-hp., complete with cable, etc. at ± \$2,500 each	\$135,000
54 scrapers at \$210 each	11,340
54 steel scraper hoppers at ± \$500 each	27,000
Total	173,340

Haulage

Standard train haulage will be used to transport the broken shale from the scrapers to the outside. Cost of this equipment should be the same as that under the section on Standard Block-Caving methods.

Cost per ton, as before, is estimated as $0.05.

Development

Development work necessary for each panel is shown in table 16.

TABLE 16. - Development work necessary for panel 180 by 1,071 feet for mining 106-foot bed of oil shale by caving method, using scrapers; 1,362,000 tons in panel

	Total	Per ton
Main haulage drift (across panel), 8x13x180 ft. at $17.61 per ft.	$ 3,170	$0.0023
Branch haulage drift, 9x10x1121 ft. at $8.49 per ft.	19,034	.0140
Supply or fringe drift, 5x7x1171 ft. at $5.53 per ft.	6,476	.0048
Scraper drifts, 36 of 5x7x160 ft., or 5,760 ft. at $5.53 per ft	31,853	.0234
Finger raises, 864 12 ft. long, or 10,368 ft. at $3.89 per ft	40,332	.0296
Shrinkage stoping, 40,000 tons at $0.70	28,000	.0205
Undercutting stoping, 150,000 tons at $0.70	105,000	.0771
Draw-set installations, 432 at $200	86,400	.0634
	320,265	.2351

The cost for general development work necessary for the block-caving method of mining the 106-foot shale bed is given in table 17. This work is charged against 72,000,000 tons of shale, or a 20-year supply at 10,000 tons a day.

TABLE 17. - General development work necessary for mining block of 72,000,000 tons

	Total	Per ton
Main entry[1], 490 ft. at $17.61 per ft......	$8,628.90	
Ventilation drift, 1,800 ft. at $8.49 per ft.	15,282.00	
Total	23,910.90	$0.0003

1/ All of main entry except 490 feet charged to panel development.

Total Plant, Amortization, and Interest

The total equipment necessary for mining 10,000 tons daily is the same as that shown under the section on block-caving with branch raises, with the following exceptions:

54 double-drum, electric scraper hoists, complete, at approximately $2,500 each	$135,000
54 scrapers at $210 each	11,340
54 scraper hoppers at approximately $500 each	27,000
Total	173,340
Total of plant cost for mining 10,000 tons, as per table 14	1,350,226
Additional	173,340
Grand total	1,523,566

The cost of the total equipment for block-caving 10,000 tons a day by using scrapers therefore is $1,523,566. Amortized over 15 years at 6 percent interest, the amount per ton for 72,000,000 tons would be $0.050.

Summary of costs

The expected mining costs are summarized in table 18. This gives a cost of $0.538 a ton compared with $0.576 for block-caving with branch raises, or a saving of $0.04 by using scrapers.

TABLE 18. - Summary of costs per ton for mining 10,000 tons daily from 106-foot bed of shale (15 cubic feet = 1 ton)

Drawing, at 100 tons per man = $4.50	$0.045
Scraping	.016
Development work and stope preparation	.235
General underground expense	.030
Underground transportation	.050
Surface labor charged to underground operations	.025
Supervision, including engineering	.027
Crushing	.030
Tramway	.020
Workmen's compensation	.010
Interest on $1,600,000 at 6 percent, and amortization over 15 years and 72,000,000 tons	.050
Total	.538

SUMMARY OF EXPECTED PROFITS IN MINING THE THREE THICKNESSES OF SHALE

Table 19 shows the profit that could be expected from mining shale under the various plans considered in this paper. It assumes, for example, a value of $1.00 per barrel of 42 gallons ($0.0238 per gallon) for the oil in the shale as delivered to the retorts, and a 95-percent extraction of the oil in the retorts. From this table it would seem that mining 5,000 tons daily from the 44-foot bed would afford the greatest profit, unless the value of the oil in the shale greatly exceeded $1.00 per barrel, in which case the caving method would be most advantageous.

TABLE 19. - Summary of profit per ton in mining various thickness of oil shale

Thickness of shale, feet	Grade of shale gal. per ton	Recovery of oil, gal. per ton	Shale mined per day, tons	Oil production, bbl. per day	Value of oil recovered per ton of shale 1/	Cost of mining shale, per ton	Indicated profit, per ton	Indicated profit, per day
20	44.3	42.1	2,000	2,000	$1.002	$1.004	Loss	-
20	44.3	42.1	4,000	4,010	1.002	.964	$0.038	$152
44	35.4	33.6	5,000	4,000	.800	.712	.088	440
2/106	3/23.8	22.6	10,000	5,380	.538	.576	Loss	-
4/106	3/23.8	22.6	10,000	5,380	.538	.538	0	0

1/ Value of oil recovered, minus cost of retorting.
2/ Using branch raises.
3/ Allowing for 10-percent dilution.
4/ Using scraper system.